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Final Report

Alternate System Analysis

WESTINGHOUSE ELECTRIC CO.
NUCLEAR ENGINEERING
HEADQUARTERS CAMPUS

Pittsburgh, PA

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1.0 Acknowledgments

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Special Thanks to all of my friends and family for their support!

2.0 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 Air Conditioning 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 with chilled water from three centrifugal chillers and electric re-heat/gas-fired burners from the VAV boxes and AHUs.

In an effort to optimize the systems of Building 1, analyses were performed involving a study of a Dedicated Outdoor Air System with three different systems in the office space. An all Active Chilled Beam configuration, an All DOAS Fan Coil Unit (aka DOAS Fan Powered Terminal Unit) configuration, and a DOAS FCU on Perimeter and ACB in Core configuration were all explored. Once the Plant loads have been reduced with these systems, the three systems will be connected to both a Central Chiller & Boiler Plant and a Hybrid Ground-Source Heat Pump. The Hybrid Ground-Source Heat Pump was explored over a typical non-Hybrid system because of its initial cost savings as well as energy savings. Initially, both a Centralized and a De-Centralized GSHP Plant were explored, however the energy modeling program could not accurately model the De-Centralized Plant—thus only Centralized Plant was extensively analyzed.

Additionally, each of these combinations of system and plant was modeled with and without a Façade Redesign (Architectural Breadth). The intention of this Façade Redesign was to reduce the thermal loads within the space. As part of the Façade Redesign, a Daylighting study was done a south facing office area. The study examined the use of a Light Shelf system to reduce the usage of artificial light in the space as well as reduce the thermal load.

The Dedicated Outdoor Air System with the all DOAS Fan Coil Unit (DOAS Fan Powered Terminal Unit) configuration proved to be the best choice for the Westinghouse Headquarters. The plant analysis showed that the Hybrid Ground-Source Heat Pump Plant option was the most beneficial system, even though it did not have the lowest Initial Cost or Payback Period—the Central Plant had both. The Hybrid GSHP Plant had the lowest emissions, lowest energy use, and lowest Life Cycle Cost. The Façade Redesign had a very beneficial effect upon the Initial Cost, Life Cycle Cost, and Payback Period for all of the systems and plants.

Since the building is owned by a developer, their biggest priority with choosing a system and plant is Initial Cost. This is the reason why the current Mechanical system has a standard VAV system with a Chiller Plant and Electric Resistance. However, according to the results of this report, a Boiler Plant would actually be a lower first cost than the Electric Resistance.

The overall best option for the Westinghouse Headquarters is Dedicated Outdoor Air System with DOAS Fan Coil Unit (DOAS Fan Powered Terminal Box) configuration and a Centralized Hybrid Ground Source Heat Pump Plant.

3.0 Existing Conditions

3.1 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. The complex Site Plan is depicted in the image below.

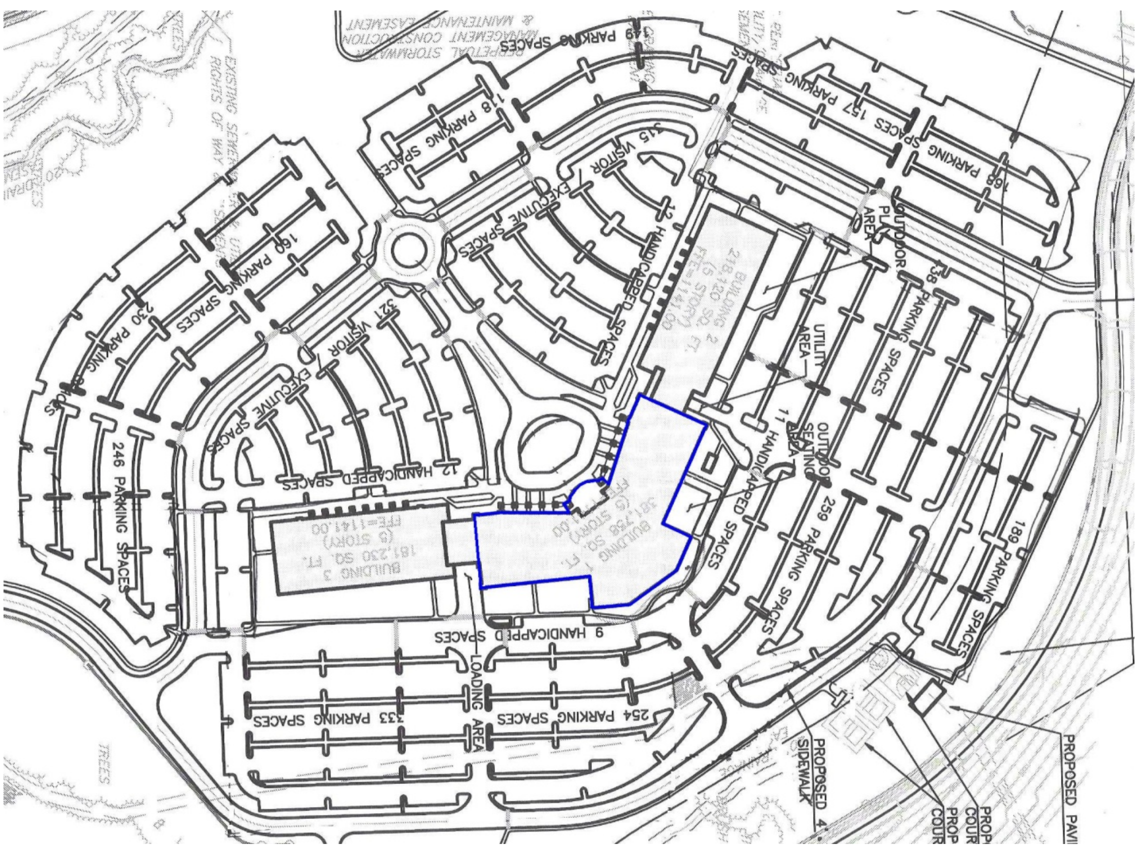


Image 1: Site Plan (Building 1 is highlighted)

3.2 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 is 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.

3.3 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 four main Air Handling Units provide pre-heating through Gas-fired Burners. These main AHU's provide the building with about 40% OA. The VAV Terminal Units have Electric Resistance Re-Heating to provide the heating for the zones. Fan Powered Boxes are used to condition the perimeter spaces.

The Tables 1 through 5 display summaries for the Air Handling Units, Chillers, Cooling Towers, CRAC Units, and Domestic Hot Water Heaters Units respectively.

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 1.

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 2.

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 3.

CRAC Unit Compliance		
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 4.

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

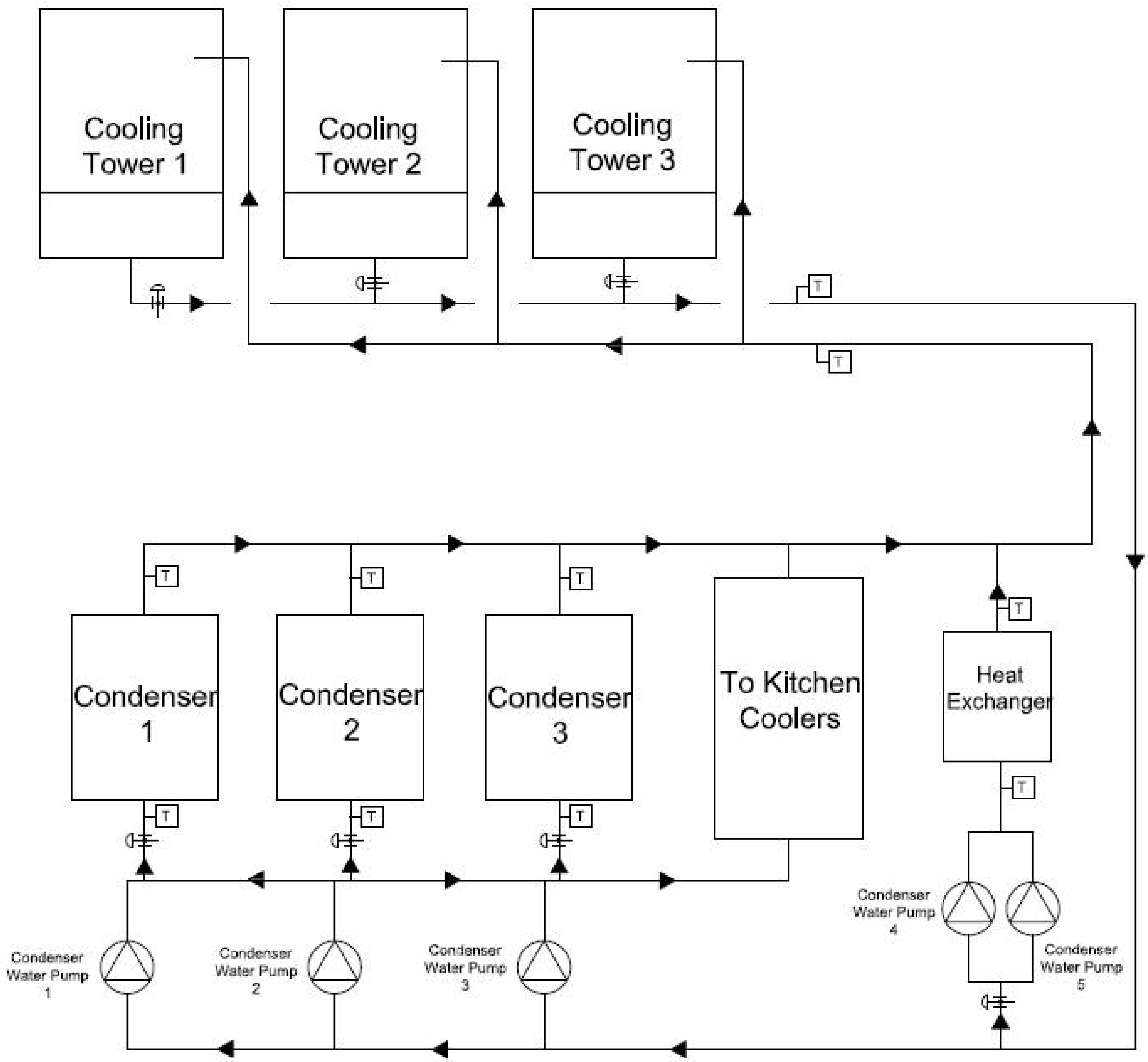
Table 5.

All of the mechanical equipment is controlled using a complex-wide BACnet Building Automation System. This will allow the operation and maintenance employees to monitor the building(s) to ensure that the systems continue to run at maximum efficiency.

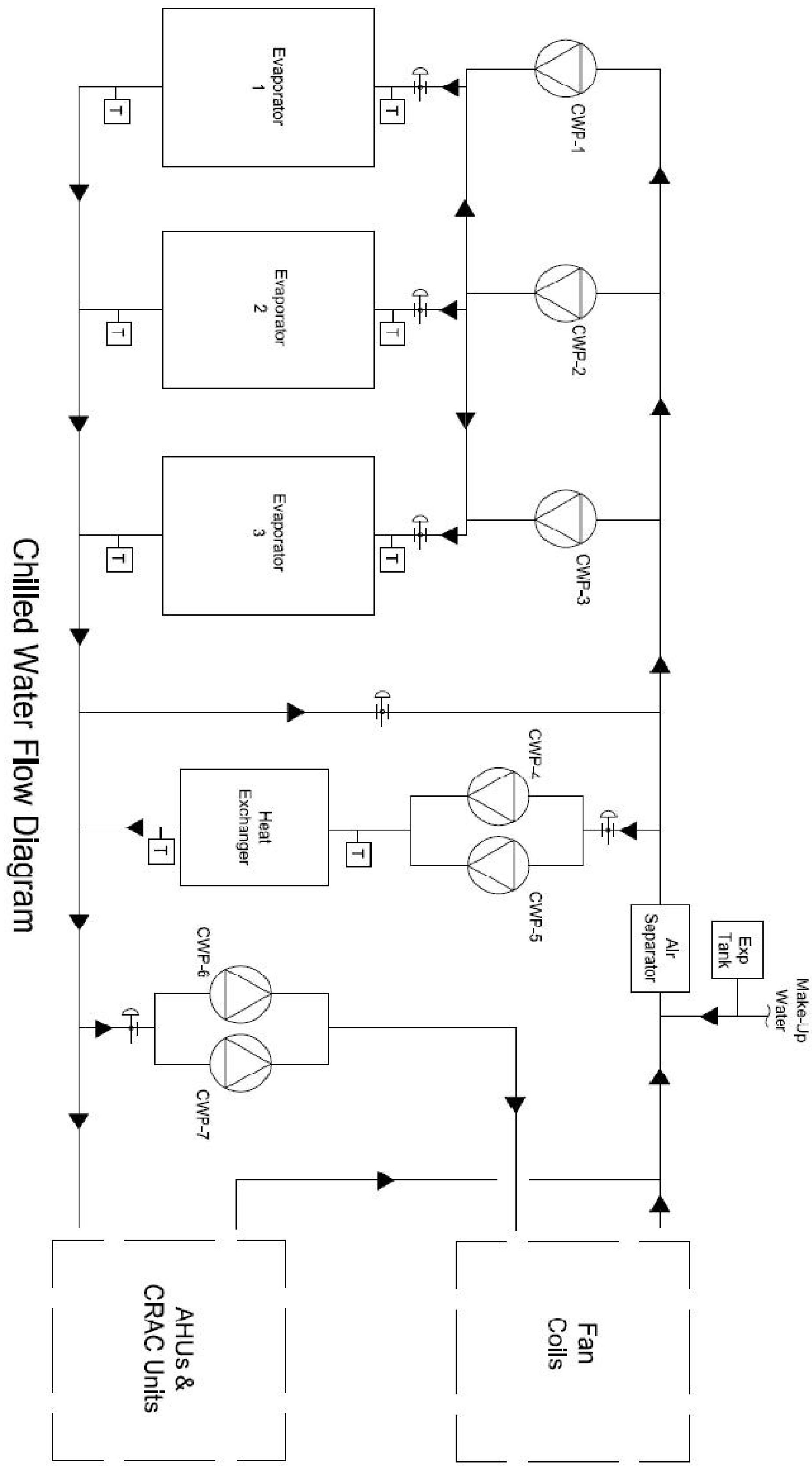
Power is provided to the site through an electric grid connection and a Natural Gas line. The 500kW back-up generator is used only in the event of a power failure.

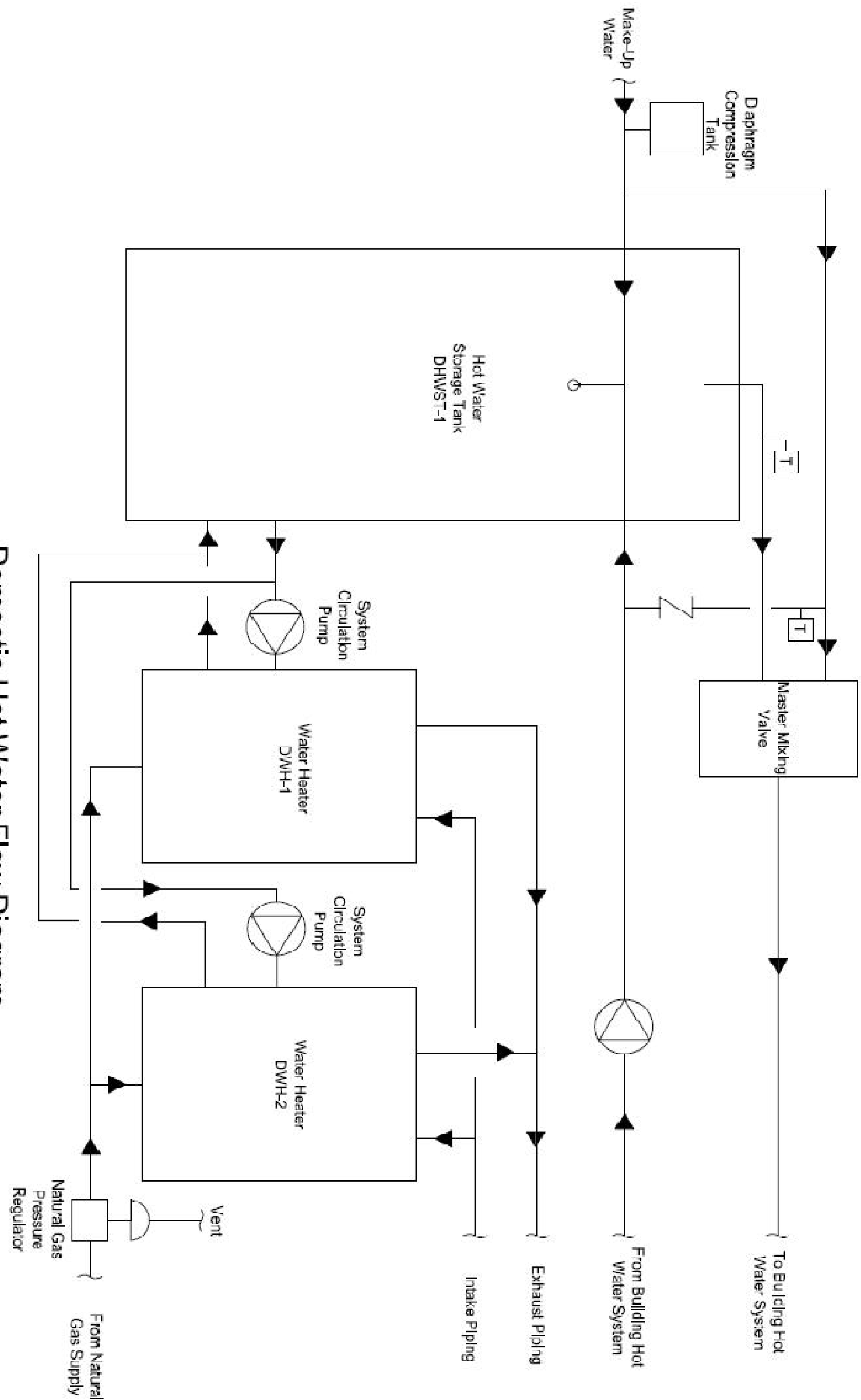
3.4 Mechanical System Schematic Drawings

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



Condenser Water Flow Diagram


Chilled Water Flow Diagram
Evaporator 1
Evaporator 2
Evaporator 3
CWP-1
CWP-2
CWP-3
CWP-4
CWP-5
CWP-6
CWP-7
Heat Exchanger
Air Separator
Exp Tank
Make-Up Water
Fan Coils
AHUs & CRAC Units



Domestic Hot Water Flow Diagram

3.5 Design Conditions

The outdoor conditions for the energy model are approximated as Pittsburgh, PA and are listed in Table 6 below.

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

Table 6.

3.6 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.

3.7 System Energy Sources

Since Westinghouse's Nuclear Engineering Headquarters is located in the Pittsburgh region, it has the benefit of having relatively low electricity prices. The utility rates used for this project are from Duquesne Light and Columbia Gas. The rates are listed in Table 7 below.

Utility Cost Information			
Electricity Demand ($/kW)	Electricity Consumption ($/kWh)		Natural Gas ($/Therm)
On-Peak	On-Peak	Off-Peak	Annual Average
3.09	0.107	0.507	1.55

Table 7.

3.8 Mechanical System Initial Cost

The approximate initial costs for the Mechanical system of the project are as follows:

-Chiller Plant: $4,000,000

-Heating Elements: $2,000,000

-VAV and FPB Units: $2,600,000

-AHUs, Plumbing, Controls, and other mechanical items: $7,400,000

The cost of the Mechanical system totals $16,000,000 or an estimated 18% of the total hard costs of the building.

4.0 Data from Previous Technical Reports

In the required Technical Reports written prior to this report, components of the building systems and performance were analyzed and discussed. These areas include an ASHRAE 62.1-2007 analysis, an ASHRAE 90.1-2007 analysis, a Heating and Cooling Load Analysis, and an Annual Energy Use Analysis.

4.1 Ventilation Requirements

To verify that the building air handling system is providing enough ventilation air for the occupancies, an ASHRAE 62.1 Analysis was performed on two of the four Air Handling Units (AHU's). For this analysis the ductwork was followed from the AHU to the diffusers to determine how much outdoor air is being supplied by the design and how much is required by ASHRAE 62.1.

The areas specific to each room were input into the equations specified by ASHRAE 62.1 to determine the amount of ventilation air required for each space. Because the system is a VAV system the ventilation air was given as a fraction of the total maximum supply air to the zone.

On average, the outdoor air fraction was found to be quite high compared to what the design documents prescribed and what most office buildings of this type generally require. The calculated OA% was 75%, which is significantly higher than the designed percentage of about 50%. This difference may be accounted for in the inaccuracies of modeling some of the high computing laboratories. Information on many of these spaces was not permitted as it was sensitive information.

The ability to model a VAV system accurately is very crucial because this outdoor air fraction will be supplied to all of the 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 conditioning that air. For this reason it is important to assure that most of the spaces have about the same requirements for outdoor air as they are receiving.

4.2 Heating and Cooling Loads

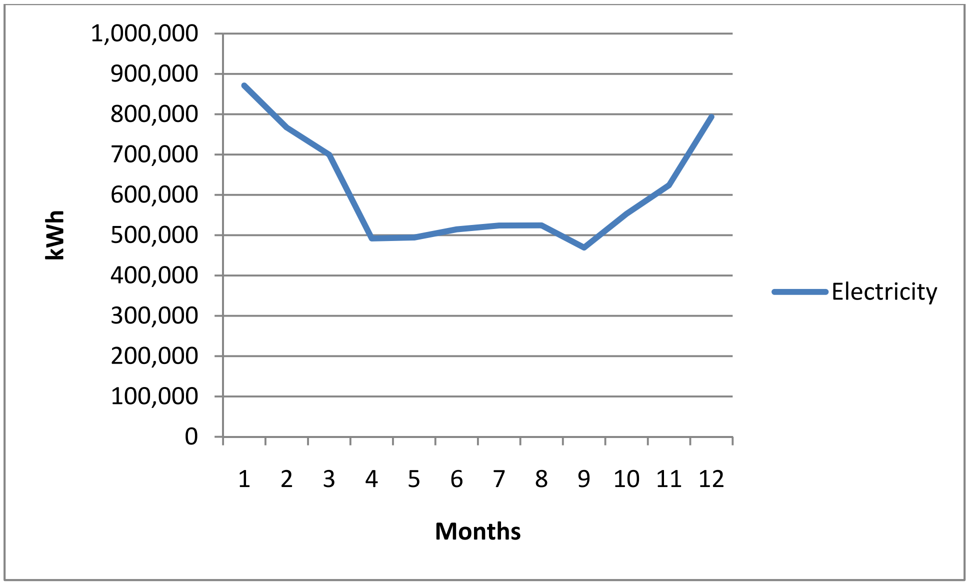
To determine the airflows, design loads on the system, and other energy values, a model was created in the Trane Trace analysis program. Room dimensions, occupancies and window areas were all input into the building simulation. This model was designed only as a block model and all input values have been calculated by hand since a Revit model was not available for this analysis.

The Trace model was also used to calculate the building's total energy use which is approximately 7.36 million kWh per year or about 50,800 BTU/SF-YR. A similar building, according to EIA, consumed about 51,500 BTU/SF-YR. Heating was found to be the largest energy user with about 31% of the total. This can be attributed to the method of primary heating—electric resistance coils in the VAV units. The use of electric resistance coils mixed with air being the thermal transfer fluid results in a inefficient method to heat a space. Other factors that could have contributed to this high heating demand are the building's location, amount of glazing, orientation and other factors.

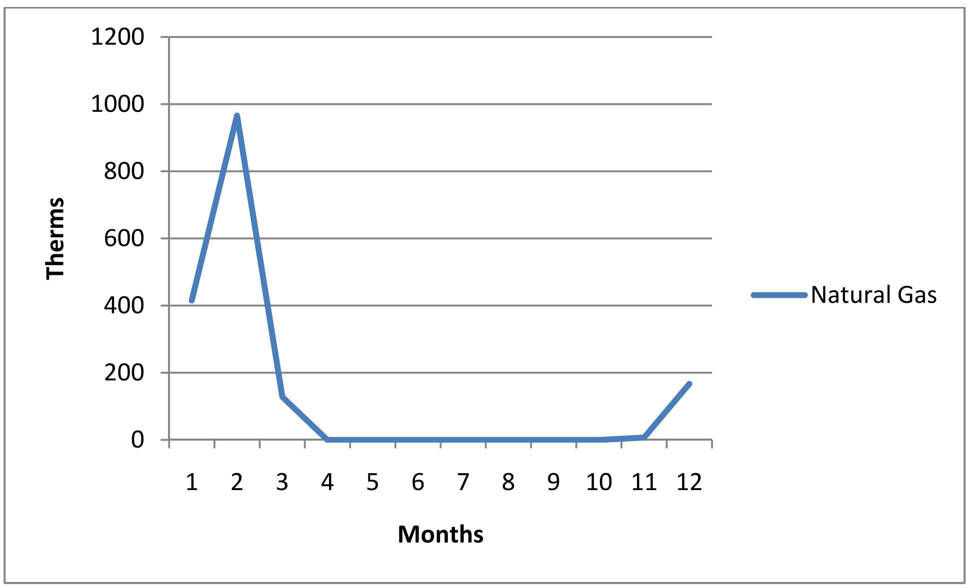
The following tables and graphs depict the energy usage of Building 1.

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

Table 8.



Graph 1. Monthly Electrical Energy Consumption



Graph 2. Monthly Natural Gas Consumption

4.3 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.

5.0 Evaluation of Current System

For detailed analysis of the system, Building 1 was closely investigated. The VAV System chosen for Building 1 is typical choice for an office building of this nature. The only information on the first cost for the mechanical system of Building 1 is the bulk system price of $16 million with an estimated $4 million for the cooling plant. However, with the VAV system specified and no special equipment, e.g. enthalpy wheel, the cost of the mechanical system should be relatively normal for a building of this type. This building is tenant-occupied and the owners were primarily concerned with low initial costs to return their investments as quickly as possible—thus a typical VAV system was the obvious HVAC solution.

The system should also have a relatively low operational cost. According to the Trane Trace model from Technical Report 2, the operational cost for the HVAC system is estimated to be $1.30/SF ($0.73/SF for energy bills and ~$0.60/SF for maintenance). This is quite similar to a similar to the $1.40/SF listed in the Energy Information Agency's (EIA) 2003 Commercial Buildings Energy Consumption Survey. The lower cost might be accounted for with the VAV system being relatively low maintenance and relatively efficient as compared to some less common systems. Another major influence is the low utility cost for the Pittsburgh area.

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, the higher floor heights and larger shaft areas effect the payback period for the owner significantly—higher floor to floor height, higher capital cost; 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, e.g. chilled beams, the ductwork can be significantly downsized. This idea was implemented in the Data Center with the CRAC Units. These units are connected to the Chilled Water loop and 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. Additionally, when the project was still in design phase, a boiler system and fin tube heating was considered but the owners did not want fin tubes because of the high churn rate of the office.

Overall, the VAV system was a good choice for a variety of reasons. The VAV system will exhibit a low first cost, high ease of construction and maintenance, and can be designed to adequately meet the needs of the building. Other systems may have been ruled out due to higher first costs. However, better economic performance may be achieved from another system. A system with a lower operational cost, more energy savings and low emissions might be a better solution for the owners.

6.0 Proposed Alternate Systems

While a VAV system is effective to meet the needs of the owner, other alternatives may be better in the long-term. To determine the best solution for Building 1, the coil loads within the building will be analyzed and options will be studied to determine load reduction relative to a VAV System. Active Chilled Beams (ACB) and Dedicated OA System Fan Powered Terminal Unit (DOAS FCU) will be the two air distribution methods used. Both of these systems will be implemented into a Dedicated Outdoor Air System (DOAS). Then these two air systems will be applied to two different plant options: a Ground-Source Heat Pump (GSHP) System and a Chiller/Boiler (Central Plant) System. Additionally, the architectural and daylighting breadths are intended to lower the external thermal load on the building. With these thermal reductions, each system/plant combination will be reduced further. The results from these studies will be compared with the design case of the VAV system with a Chiller and Electric Re-heat. All system/plant combinations will be compared on several parameters.

6.1 Dedicated Outdoor Air System

The best step to making a building efficient is to reduce the loads. In general, this is the most cost-effective method to gain overall efficiency. For example, selecting a very high efficiency chiller might not be the best choice if the loads have not been addressed. In that case, the chiller does not need to be as large as it is to meet loads that are dealt with more efficiently. By meeting the loads with less input energy required, the chiller can be downsized, increasing savings.

Since the building is largely office space, a major proportion of this analysis will focus on reducing the coil loads of these spaces. A Dedicated Outdoor Air System, or DOAS, will be explored to reduce the load on the mechanical system. DOAS is beneficial for several reasons of energy savings, smaller system, and improved indoor air quality. Two sensible cooling methods will be explored: Active Chilled Beams (ACB) and DOAS Fan Powered Terminal Units, commonly referred to as DOAS Fan Coil Units (DOAS FCU). One study will explore the usage of only the Active Chilled Beams throughout the office areas. Another will use only DOAS FCUs throughout the office areas, while a third study will use both systems in tandem—DOAS FCUs for the perimeter and Active Chilled Beams for core office spaces. The tandem system will be explored because of the large amount of heating required for the building and FCUs are much more efficient for heating than ACBs. Other major steps will be taken to reduce external gains to these spaces including solar shading and façade re-design.

By creating an energy model of these systems, a comparison can be made with the existing VAV system with respect to initial cost, total cooling and heating load on the plants, payback period, construction impact, and indoor air quality.

6.2 Ground Source Heat Pumps

Once the loads have been reduced or adjusted, the design case of current chiller plant and electric re-heat can be compared to the Ground-Source Heat Pump option. Applying the loads from each of the air systems allows the determination of overall building performance.

With the Westinghouse complex located in the middle of a large piece of property, there is a considerable amount of open land that would be suitable for a ground-source heat pump system. A hybrid heat pump system will be explored using a supplemental Cooling Tower. This strategy will greatly save in initial costs without reducing the efficiency of the plant too much. A back-up Boiler will be implemented; however, the Heat Pump System will be sized appropriately so that the Boiler should not have to handle any excess loads.

The GSHP System will be explored in a two separate methods—a centralized plant and a distributed plant. The centralized plant will be three staged Heat Pumps sharing a condenser loop (ground loop) and conditioning the building with a 4-pipe system. The distributed plant will be smaller Heat Pumps located throughout the building to handle only local loads. And similarly to the centralized plant, these Heat Pumps will share a condenser loop to take advantage diverse loading.

A ground-source heat pump system has a significant initial cost however maintenance costs are generally low and the life of the system will outlast almost any other system. A GSHP system will also have an impact on the construction schedule depending on the depth and number of bores needed to meet the building’s load. The GSHP system will be implemented into the Active Chilled Beam system as well as the DOAS Fan Coil Unit design.

6.3 Central Plant

Another option for providing heating and cooling to the building is the use of a Chiller and Boiler Plant, or a Central Plant. The existing mechanical system already has a Chiller Plant, but the heating is done with Gas-fired pre-heat in the main AHUs with electric resistance in the terminal units. However, with the addition of a Boiler Plant and a Hydronic System, the spaces will be able to be conditioned much more efficiently with less primary fuel usage. And with the load reduction from the DOAS design, the Chiller Plant will use much less electricity.

This system will be implemented in the Active Chilled Beam system as well as the DOAS Fan Coil Unit system. The two configurations will be compared with the existing plant along with the Ground Source Heat Pump Plant upon initial cost, energy usage, utility costs, and emissions.

6.4 Architectural Breadth

The redesign of the façade and overall exterior response of the building will be the focus of this breadth. A study will be done on each of the facades to examine the appropriate response to each of their orientations. The major heat gain/losses on each façade will be tabulated to develop the best strategy of redesign. The concept behind the redesign is to be sensitive to the existing architectural style while still effectively improving the thermal performance of each facade.

6.5 Lighting Breadth

In addition to an architectural breadth, a lighting breadth will be done with an overall goal to reduce the lighting requirements for the open office spaces. The current lighting design is already quite energy efficient with the use of low-wattage fixtures; however this breadth will focus on other aspects of lower lighting energy usage. Light shelves will be explored to possibly reduce the need for as much artificial lighting. With the implementation of a Dimmer Control System in addition to the light shelves, Westinghouse should be able to save a considerable amount on energy. These light shelves can be projected from the building's façade to also act as a solar shade. The implementation of solar shades has an architectural aspect to them as they will be a prominent feature on the building's façade.

Overall, the addition of light shelves may be an inexpensive addition with major impacts to the design of the building's mechanical system.

6.6 Integration of Studies

All of the above depth and breadths are integrated in such a way that the overall combination of efforts will be toward a more efficient system. In this manner the architectural and daylighting breadths can be combined with the system and plant analyses to determine the best overall configuration for the building.

6.7 Basis of Comparison

When considering options for redesign of a system, it is important to lay the guidelines for determining whether a redesign is an improvement. The following are the criteria used to meter the success of the alternate system analysis:

6.7.1 Initial Cost

Sometimes the most critical factor for the Owner is the initial cost. This value, while important from a feasibility standpoint, needs to be balanced with the other associated costs when the building will be operated for a relatively long period of time. The Westinghouse Headquarters will be tenant occupied for at least 15 years, and should be designed to be occupied for at least the next 40 to 50 years.

6.7.2 Lifecycle Cost

Lifecycle cost will be computed by using the tabulated utility costs combined with maintenance costs. Figures for maintenance costs are estimated from previous projects with similar systems. The Lifecycle Cost will more adequately represent the overall cost of one system versus the existing baseline system.

6.7.3 Construction Impact

Impact on construction schedule will be rated from least to greatest impact. This will include discussions of the timeframe of each system's installation. Even though this project is being delivered as a Design-Bid-Build, keeping the construction low will lower the overall cost of the project.

6.7.4 Indoor Air Quality

Indoor Air Quality of the office air system options will be compared on a qualitative level based upon air supply. The baseline of this comparison will be the VAV system for the office space.

6.7.5 Energy Use

The projected Energy Use will be compared using values from an energy model. These values will be obtained while maintaining the same indoor thermal comfort insuring that the systems are capable of providing a comfortable environment.

6.7.6 Environmental Impact

Environmental Impact will be assessed quantitatively depending upon the Energy Used. Environmental Impact is moving closer to the forefront when considering system design. Many mandates and incentives exist to limit the negative impacts of humans on the environment and more are planned for the future.

7.0 Dedicated Outdoor Air System

Dedicated Outdoor Air Systems can be a very effective method to not only increase a building's overall energy efficiency but can dramatically increase the Indoor Air Quality.

A DOAS system needs to supply much less air than a typical VAV system (rule of thumb is about 20% of a conventional system). This reduction in supply air means a downsizing of ductwork and fans. Additionally, the downsizing of ductwork results in lower floor-to-floor height requirements—saving additional construction costs. With the use of DOAS, the heating and cooling is decoupled from the ventilation air. Since water has a much better heat capacity than air, the energy requirements for the mechanical system will be much less.

With ventilation and space conditioning decoupled, the DOAS Air Handling Unit can accommodate 100% of the space latent loads, 100% of the outdoor air latent loads, and near 30% of the total sensible load with the use of a Total Enthalpy Wheel. With all of these loads handled the Dedicated OA System AHU, it is estimated that only about 40% of the design chiller load must be handled by the parallel sensible only cooling system.

According to Stanley Mumma, compared to a conventional VAV system, which can have issues with properly ventilating all the spaces with enough outdoor air, a Dedicated OA System can place the proper ventilation air quantities into every space. Also, a VAV system generally uses 20-70% more outdoor air than is required in an effort to assure proper ventilation air distribution in all air systems than is required with DOAS. Cooling and dehumidifying the high OA quantities in the summer and humidifying and heating the air in the winter is an energy intensive proposition. Additionally, VAV systems always use more terminal reheat than DOAS at the same air temperature because VAV requires more air.

For this analysis, the Dedicated OA System was modeled using a Total Enthalpy Wheel for latent conditioning. However, due to the parameters available in Trane Trace, the wheel can only be sized to a certain load. This load is selected by the simulation, not by the user. Thus, the simulation included a condensing coil within the unit as well. Even with the inaccuracies, the simulation of the DOAS provided good results within the range of CFM and Cooling tonnage which were described above.

7.1 Active Chilled Beam System

Active Chilled Beams are a cutting-edge application of an old technology; the induction unit. They are more sophisticated, but operate on the same premise of buoyancy of air at differing temperatures. By using this property, fan energy can be reduced for the movement of air across the cooling coil. The Active Chilled Beam uses high pressure nozzle to create turbulence and to better mix the re-circulated air. This turbulent mixing allows for warmer water temperatures (55 to 60 deg F) to have the same cooling as a conventional VAV unit (~45 deg F). Active Chilled Beams were selected over a Passive system because of their higher cooling capacity and the Active unit can provide ventilation air as well. Passive chilled beams only induce room air to cool it, ventilation air must be provided by other means. There are some disadvantages of Active Chilled Beams. First, they have difficulty heating a space and with Westinghouse would definitely require supplemental perimeter heating. Secondly, most contractors and commissioners have little experience with them. Also, Active Chilled Beams are condensing water in dangerous location. However, a study was done with Chilled Beams in which the beams were at 14°below the dew point for 8.5 hours with no condensation falling. So the risk of condensation falling on critical equipment does have a flex temperature region—but not recommended. The image below depicts an Active Chilled Beam in cooling mode.

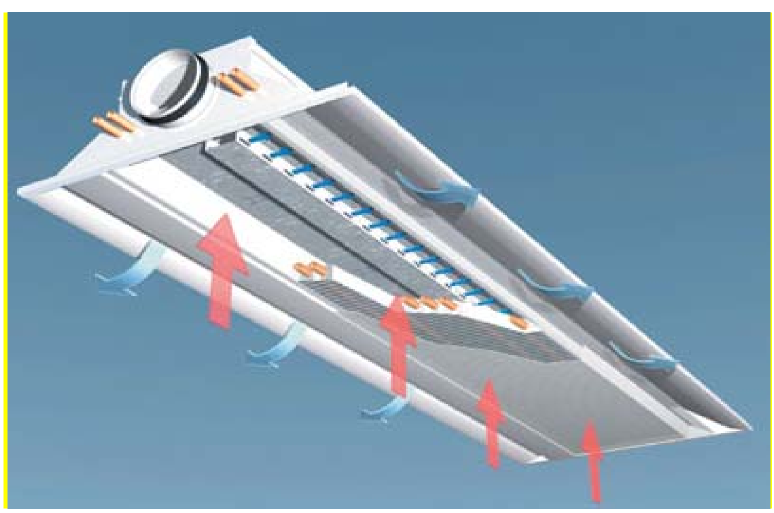


Image 2: Active Chilled Beam in Cooling Mode

7.2 DOAS Fan Coil Unit

DOAS Terminal Units or Fan Coil Units (DOAS FCUs) have not had the wide spread popularity as Chilled Beam but still provide several advantages that even Chilled Beams cannot match. DOAS FCUs have a non-condensing cooling coil (and heating coil in this design) in the induction inlet of the box. Because Terminal Units are already common, the installing contractor and maintenance staff will be dealing with known technology. Similarly, this technology results in significantly lower zone cost. Unlike an Active Chilled Beam system, a DOAS FCU system would be a VAV system.

DOAS FCUs can be very useful for spaces that may need heating as well as cooling i.e. perimeter spaces. And with the Westinghouse Headquarters, the demand for heating is quite close to the cooling demand. Thus a single DOAS Fan Coil Unit can both heat and cool, and provide required ventilation air. The FCUs can be ducted to several spaces, unlike a Chilled Beam, as a result one unit can service several enclosed spaces. Likewise, with the DOAS Fan Coil Unit can be located over a corridor where the threat of condensation will not damage the office equipment. The basic concept of a DOAS FCU is very similar to a VAV Terminal Box but with the supply duct be sized only for the zone's ventilation rate. And unlike an Active Chilled Beam, the DOAS FCU does not use a high pressure induction to condition but simply increasing the re-circulated air. The image below depicts a DOAS Fan Coil Unit.

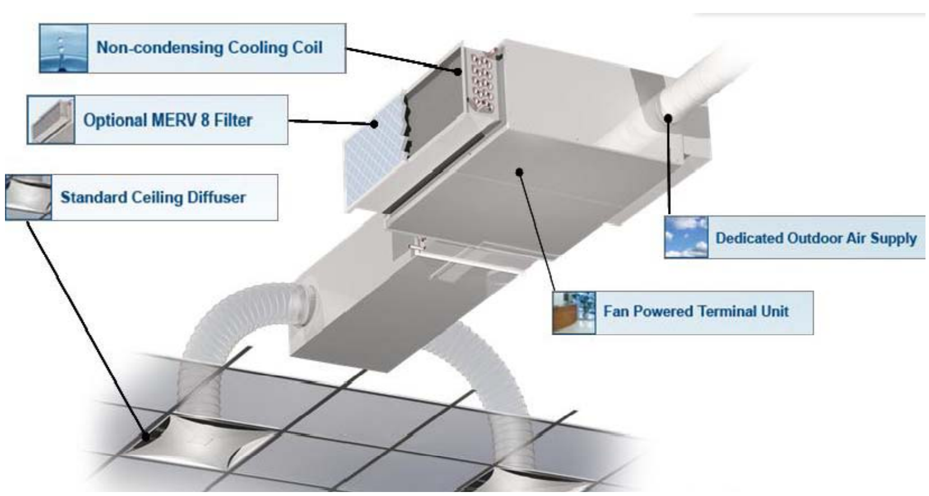


Image 3: Dedicated Outdoor Air Fan Coil Unit (Fan Powered Terminal Unit)

7.3 System Modeling

Both systems were modeled using Trane Trace Energy Modeling. Scenario 1 with all Active Chilled Beams in the office spaces was modeled with Active Chilled Beams with Wall Convectors as supplemental heating. For the Dedicated Outdoor Air System, a Total Enthalpy Wheel was modeled. It should be noted that Trane Trace does not allow a user to specify the size of the wheel—only its effectiveness. Thus, the energy model included a condensing coil within the Air Handling Unit to handle the remaining latent load. With the addition of another set of coils in the AHU, the cooling and heating loads increase significantly.

Scenario 2 and 3 were modeled very similarly to Scenario 1 with the DOAS Fan Coil Units being added. Unfortunately, Trane Trace did not have a DOAS FCU prescribe in its library. However, with the assumption that it would work similarly, a 4-pipe Induction Unit was used to model the DOAS FCU. Like the DOAS Fan Coil Unit, the 4-pipe Induction Unit has the ability to heat and cool, has a fan within the terminal, and is served by a primary AHU.

7.4 Results

The following table has the total supply air required for each of the systems. As shown, the three re-designs have slightly varying System CFM. This could be explained with small inaccuracies within the Energy Modeling program or inputs. The approximate reduction of the Dedicated OA System was 215,000 CFM or a 73% reduction in total CFM required. In terms of duct size this is going from a 40x25 duct to a 40x10 duct.

System	System CFM	% OA	CFM Reduced
Chilled Beam	80,100	100	213,500
FCU/Chilled Beam	78,700	100	214,900
Fan Coil Unit	77,600	100	216,000
*VAV	293,600	40	-

Table 9: System Size

With these three different air systems, we can see three relatively different results in terms of energy use. The following table shows the energy use in terms of cooling and heating required by the plants. As seen, Scenario 1 with only Active Chilled Beams being used within the Office Space requires the least amount of cooling with about 843 tons. Both the all DOAS Fan Coil Unit and perimeter DOAS FCU layouts actually result in higher cooling than the existing VAV system with 1-7% more cooling required. This higher cooling requirement could be a result of the assumption that the DOAS FCU system could be modeled as a 4-Pipe Induction Unit. The significant improvement over the existing VAV system is seen in the heating load with all three re-designs requiring about 6800 MBH or 28% less than the VAV system.

System	Cooling Tons	Heating MBH
Chilled Beam	842.9	6974.6
FCU/Chilled Beam	938	6803.7
Fan Coil Unit	996.4	6610.3
*VAV	928.9	9407.8

Table 10: Cooling and Heating Load per Air System

The Active Chilled Beams pose a possible problem with its density. Certain applications of ACBs are simply not possible because there is not enough ceiling area. To examine this possibility for Westinghouse, the two layouts that have ACBs were studied to see if the needed ACBs is greater than the area available for them. The below calculation is this study.

Active Chilled Beam = 100.0 W/SF of ceiling area

Core Only = 450.1 Tons x 3500 W/Ton x 1/100 SF/W

Core Only = 15,754 SF required

216,088 SF available

ACBs will use **7.3%** of the ceiling in the Core

All Office Space = 842.9 Tons x 3500W/Ton x 1/100 SF/W

All Office Space = 226,935 SF required

356,076 available

ACBs will use **8.3%** of the ceiling in the Office Space

In both scenarios only a small portion of the ceiling space is required to sensibly cool. With these smaller ratios, there should not be any conflicts with lighting layouts or any other ceiling function. In many buildings, the density of cooling required is much higher and ACBs can take up 60 to 80% of the ceiling. In these cases, it would be worth using Integrated Service Beams as well as Active Chilled Beams. The Integrated Service Beams have lighting, cabling, conduits, voice and data services, etc.

Additionally, using Chilled Beams will have a major impact on the aesthetics of the spaces and the architect might have a problem. Also, with a reduction of Acoustic Ceiling Tile, the acoustics of the space should be closely examined to ensure the reverberation time is low enough.

7.5 Indoor Air Quality

Indoor Air Quality is a difficult air characteristic to quantify, but a very important one to consider. The Active Chilled Beam system would have a best IAQ over the DOAS FCU and the existing VAV system. This is because the only air supplied to the space is outdoor air which means that there is no chance for a decrease when the load in the space decreases.

With the DOAS FCU, although the ventilation air is 100% outdoor air, the Terminal Unit uses its air dampers to control the conditioning of the space. The chance of the dampers being not set properly is still a threat to the Indoor Air Quality. Thus, if all the DOAS FCUs have their dampers properly set, the IAQ of the DOAS FCUs will be equivalent to the Active Chilled Beam.

This is not the case for the existing VAV system. Similarly to the DOAS FCU, the dampers will adjust when the space load fluctuates to adequately condition the space. And like the DOAS FCU, the existing VAV unit dampers may be incorrectly set and could inadequately supply enough ventilation air. However, unlike the DOAS FCU, the existing air system mixes return air with the ventilation air which lowers the IAQ of the building by re-circulating possible contaminates.

Therefore, in terms of Indoor Air Quality an Active Chilled Beam system would be the preferred system selection. If Active Chilled Beams are not possible, a Dedicated OA System Fan Coil Unit could provide similar IAQ to the Active Chilled Beam but would need closer maintenance.

8.0 Ground Source Heat Pump

With approximately 1,598,000 SF (36.7 acres) of the property being covered by asphalt parking, a ground-source heat pump will add no marginal site disturbance. The GSHP system could provide a considerable amount of energy savings because of the near constant temperature of the earth (52°F in the Pittsburgh region).

In this hybrid system, the Ground Loop is sized to handle the peak heating load. It was determined that the peak heating load will be less than the peak cooling load (see demand graph below), thus a Cooling Tower was sized to handle the remainder of the cooling load.

For this project a water-glycol Closed Loop will be used instead of an open loop. The closed loop prevents the need for a heat exchanger which lowers the ground loop's efficiency and increases the plant's maintenance costs. The ground loop uses thermally fused high-density-polyethylene (HDPE) 1 inch U-tubes. Since this will be a ground source and not a water source system, grout is injected into the bored to increase the heat transfer from the tubing to the ground. In terms of efficiency, a typical GSHP system can perform at a COP of 6.0 to 6.5 in cooling mode; whereas an air-cooled chiller has a COP of around 4.1. In heating mode, the COP of the Plant is closer to 4.4.

8.1 Centralized Plant

8.1.1 Characteristics

A central plant is the most expensive ground source heat pump configuration with larger and more extensive piping headers, central control, and added pump capacity. However, a central plant is easiest to integrate with the prescribed hybrid system (parallel with Cooling Tower). Also, this system is easiest to maintain which results in lower maintenance costs.

8.1.2 Schematic

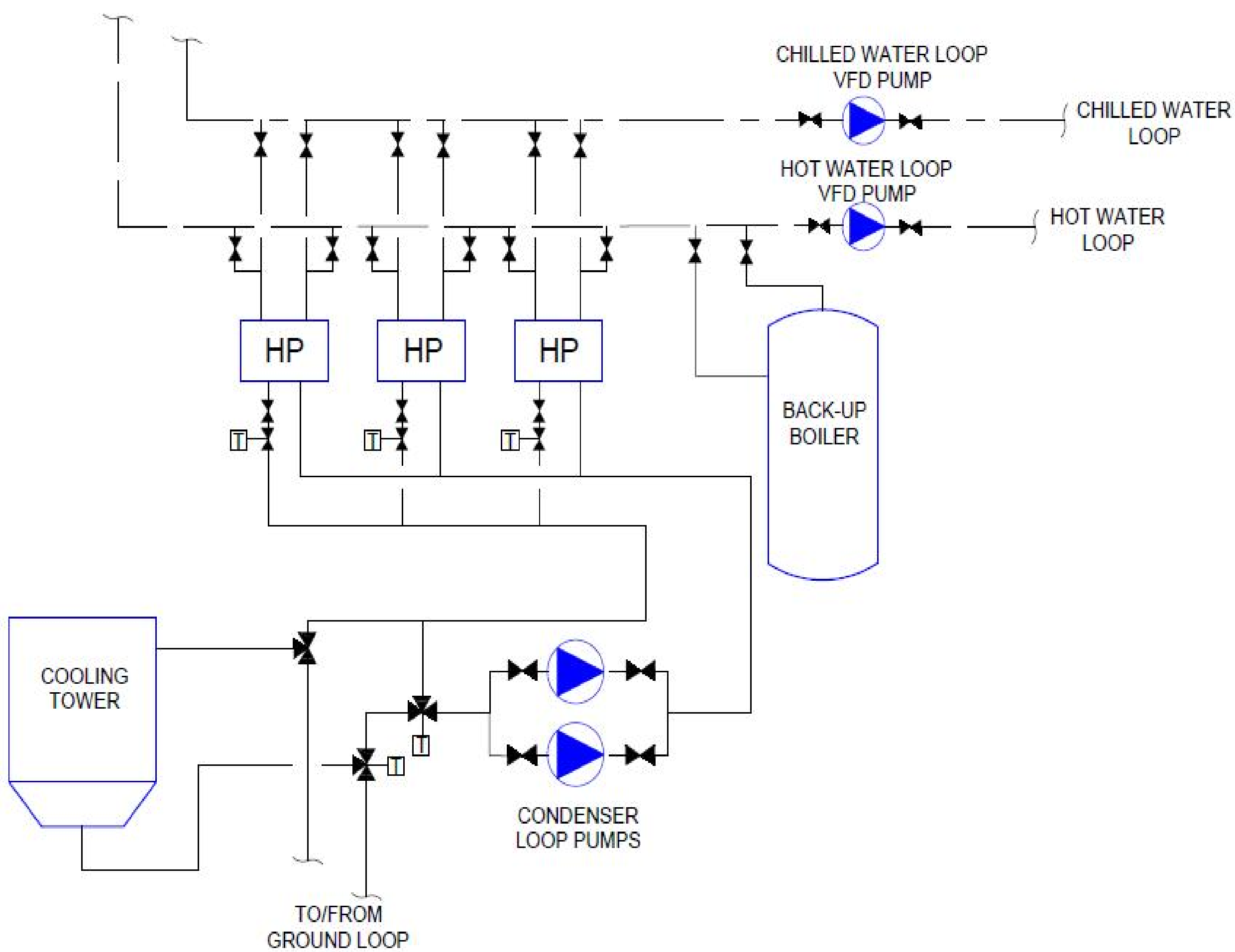


Image 4: Centralized Ground Source Heat Pump Plant

8.1.3 Ground Study

With a ground source heat pump system, the geological make-up of the ground can make or break the viability of the system. Certain geology like bedrock can make the initial cost of a ground system not feasible. A ground study for Westinghouse's structural design, it was found the half of the property had bedrock close to the surface. With this, it was assumed that half of the parking area was also over bedrock and therefore only half could be used for a ground source system or about 800,000 square feet.

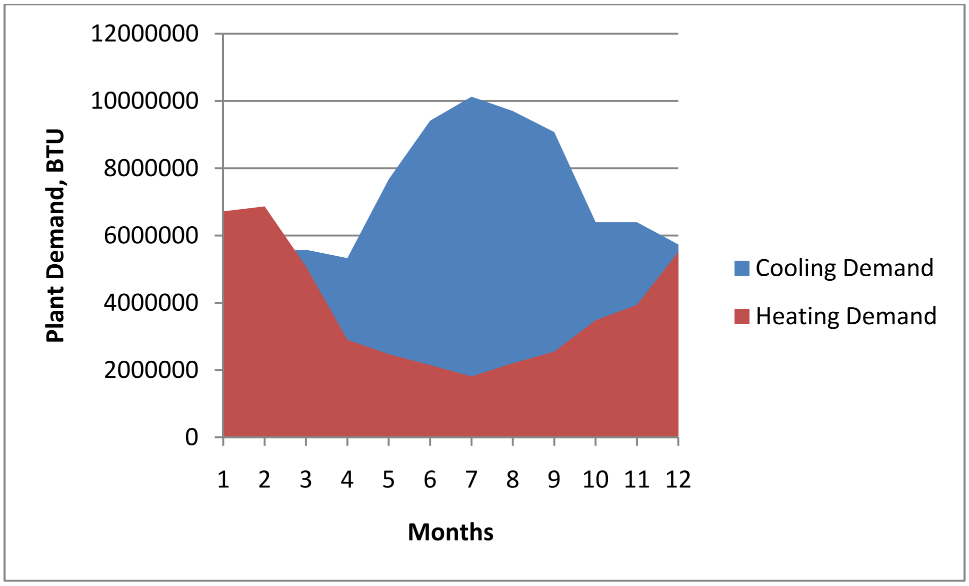
When installing the vertical bores, it is common practice to allow 20 feet in between each bore or 400 SF per bore. So as a limiting factor, only 2,000 bores can be placed on the site. Typically bores are 200 to 400 feet in depth and result in approximately 1 to 2.5 tons per bore. Therefore, with initial cost being a non-issue a 2,000 ton ground source heat pump system could be implemented.

8.1.4 Energy Use

A ground source heat pump relies on the constant temperature of the ground to use as a heat sink/source. With the ground warm in the winter and cool in the summer, the delta T between the ground and the condensing loop will provide a relatively efficient system. A conventional thermal system relies on Cooling Towers as a heat sink. However, the performance of a Cooling Tower relies on the ambient air dry bulb and wet bulb temperatures. In a rather humid region like Pittsburgh, the performance of a Cooling Tower can be diminished in the summer time.

8.1.5 Ground Source Heat Pump Sizing

Sizing of the GSHP System correctly is essential for the system's energy savings to pay off. The three Heat Pumps were sized so all three could handle the warm season's cooling demand, while sized to also handle the heating and cooling demand in the occupied winter mode with a 2 to 1 configuration. The Heating and Cooling Demand is shown in the graph below. As seen, the cooling demand is higher than the heating for all of the year except January and February. The cooling peaks at 843 Tons and the heating peaks at 6723 MBH. The three heat pump sizes are shown in the table below. The three sizes were chosen to meet the demand curve as best as possible throughout the year. A 600-ton Heat Pump would possibly need to be custom made because the largest size found in literature was 500 tons.



Graph 3: GSHP System Demand

Heat Pump Plant	Size	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
HP-1	600	C	C	H	C	C	C	C	C	C	C	H	H
HP-2	350	H	H	C	H	H	H	H	H	H	C	C	C
HP-3	350	H	H	C	C	C	C	C	C	C	-	C	C

Table 11: GSHP Plant Configuration

In a hybrid system, the Cooling Tower is sized to handle the peak loading of the cooling. The difference between the peak cooling and peak heating is 270 Tons. Therefore the Cooling Tower will be sized for 270 Tons of Cooling. The use of a Cooling Tower is important for two reasons. First, the initial cost of the GSHP system is reduced significantly. And secondly, it is very important to balance the heat transfer to the ground. If a geothermal system only was used for cooling, the ground temperature would slowly rise. With the temperature rise, the delta T for the heat exchange will be less, thus lowering the capacity of the system. The addition of a Cooling Tower will not increase the energy usage of the system too dramatically since it is sized for only the peak cooling load which is rarely hit. Actually, according to the Trace results, the Cooling demand only crests 66% of the peak less than 5% of the time.

8.1.6 Life Cycle Costs/Maintenance

The following Table compares the Utility Costs for the first 15 years associated with a Hybrid GSHP System to the All GSHP System and Existing Chiller/Electric Resistance.

System	kWh $	kW $	Total $	Utility $/SF/YR	15 Year Savings $
Hybrid GSHP Plant	5,881,860	433,335	6,315,195	1.15	4,652,970
GSHP Plant	6,150,000	450,000	6,600,000	1.18	4,368,165
*Existing Plant	9,957,105	1,011,060	10,968,165	2.00	-

Table 12: 15-Year of GSHP Utility Costs

A GSHP system typically requires a maintenance cost of around $0.20/SF/YR. Compare this to a conventional plant's maintenance cost of around $0.40/SF/YR. That results in a savings of $72,000 a year for Westinghouse.

8.1.7 Emissions

One of the main reasons a GSHP System was explore is because of its low energy usage. Westinghouse, as a company, is an industry leader in energy system design. And if their headquarters is not an energy efficient building, then that would only hurt their reputation. Likewise, it would be wise of them to set the standard for other buildings and reduce their carbon footprint on the world. A Geothermal system uses so much less energy and results and results in a significant pollution reduction.

8.1.8 Initial Cost

Initial cost for a ground source heat pump system is difficult to calculate without entering into a construction management breadth. However, the initial cost can be estimated from previous projects. It is estimated with the location of the property of the grove of a hill, the bore depth required is approximately 350 feet. And with estimation of 150 ft/ton, each bore should handle about 2.33 tons—to anticipate lower performance, a value of 1.75 tons/bore will be used. Using figures from previous projects, this boring scheme will result in approximately $4,000/ton for the bore field. For the Heat Pump Plant equipment costs, a similar project ended with an equipment cost of $7,530/ton. Thus, the initial cost will be approximately $11,530/ton with the Hybrid GSHP slightly lower and the all GSHP slightly higher.

8.2 De-Centralized Plant

8.2.1 Characteristics

Like the Centralized Heat Pump plant, the De-centralized plant can take advantage of load diversity since the heat pumps share a common ground loop. A de-centralized system had several advantages-- they are easy to control, can be used in larger buildings, and are relatively inexpensive. Also, in terms of heat pump systems, the de-centralized design is the most commonly implemented.

8.2.2 Schematic

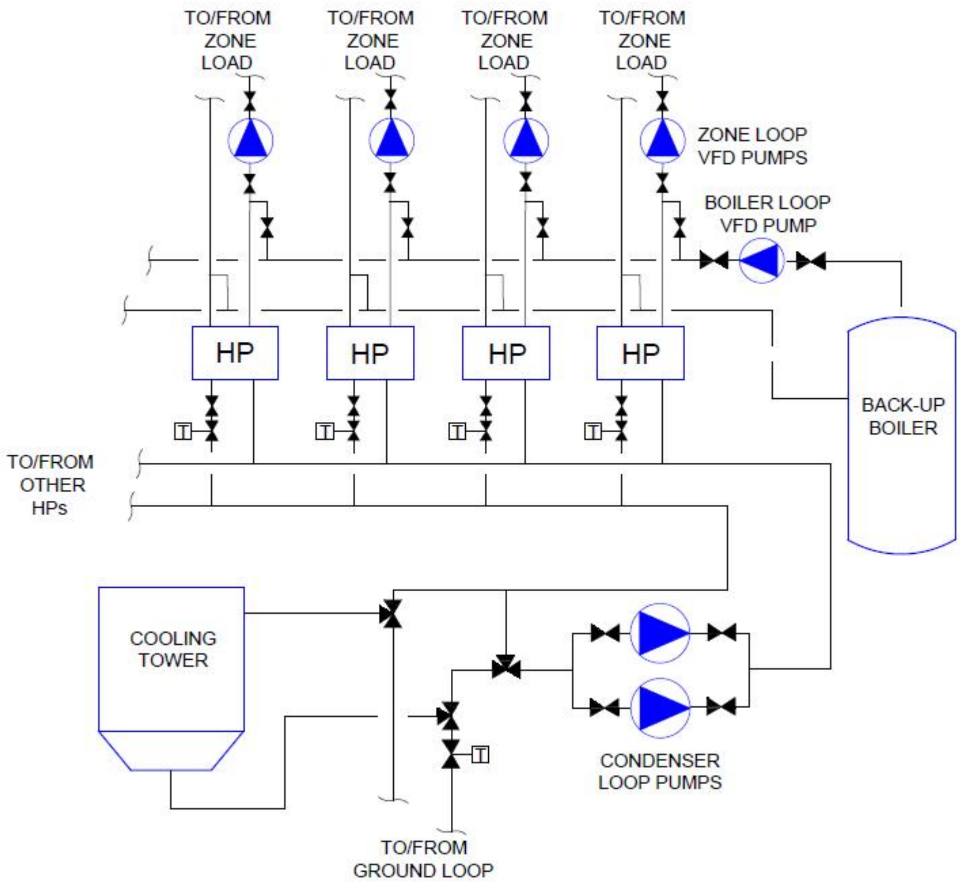


Image 5: De-Centralized GSHP Plant

8.2.3 Energy Modeling Inaccuracies

Unfortunately, Trane Trace Energy Model lacks somewhat in the field of modeling Ground Source Heat Pump Systems. The Centralized Plant was easily modeled as a water-to-water heat pump. However, the distributed GSHPs can only be modeled as water-to-air heat pumps. Also, in order to Trace to run properly, every unitary heat pump requires its own condenser loop, thus does not take into consideration the advantages of load diversity. Other modeling programs like Design Builder have better GSHP modeling capabilities, but were not able to be explored in time for this report.

8.2.4 Life Cycle Costs/Maintenance

The Life Cycle Costs of the De-Centralized system would be slightly less than the Centralized system. This assumption could be made because the distributed systems could be controlled easier and can be kept closer to the full load. Maintenance costs would be higher than the Centralized simply because there are more units to inspect and maintain.

8.2.5 Initial Cost

The Initial Cost should be lower than the Centralized Plant. The small tubing and headers required for the ground loop would neglect the increase in costs for the equipment—the larger heat pumps are cheaper on a per ton basis.

9.0 Central Plant

9.1 Chiller Plant

The current Chiller Plant has three staged Centrifugal Chillers. The same chiller plant was used for the Central Plant design with the only difference being the sizing. The current Chillers are quite efficient with a NPLV of 0.505 kW/Ton and a Full Load Efficiency of 0.547. With the redesign of the air system to be a Dedicated OA System, the size of the Chiller Plant dropped by 28% with the Active Chilled Beams.

9.2 Boiler Plant

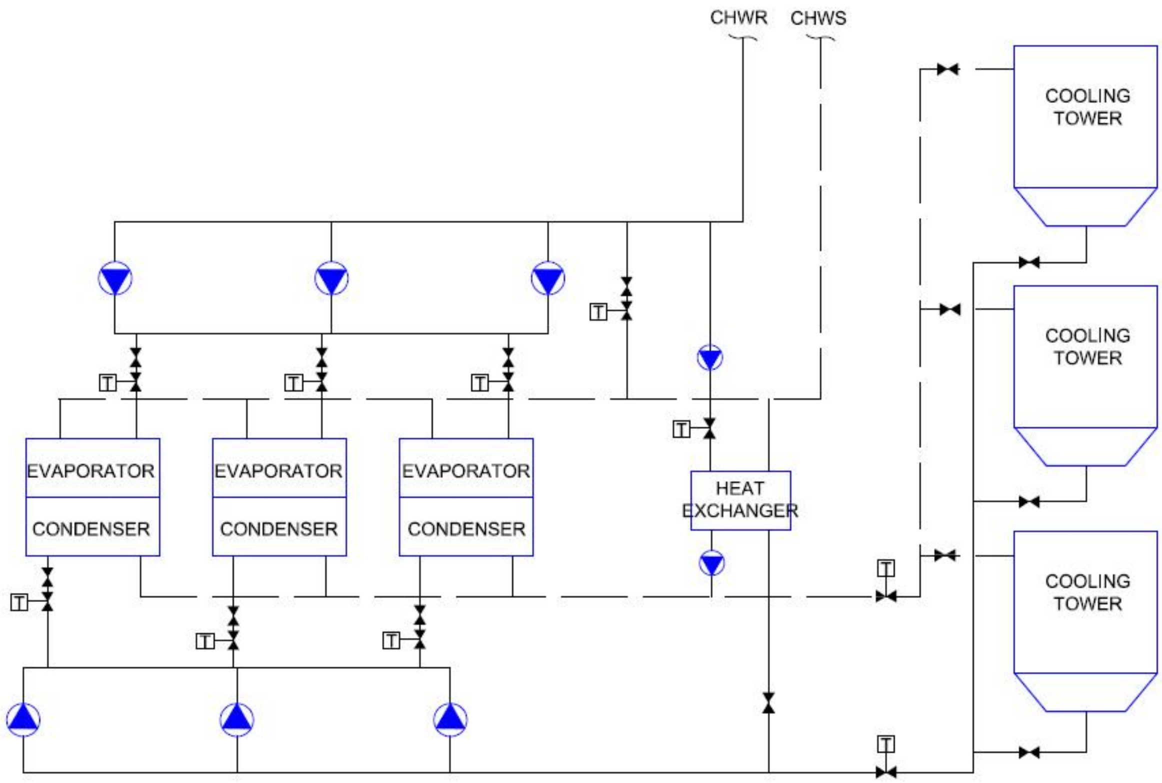
The existing mechanical system has electric resistance as its primary heating plant. The selection of electric resistance was from it low initial cost since it is easy to install, does not require any specialized contractors and does not require piping which can be very expensive. However, electric resistance has difficulty effectively heating a space. This inefficiency results in much higher energy usage for the building. Heating constituted 32% of the energy usage of the entire building. There are several alternatives to this heating method that would be more efficient and save the Owner significantly over the course of the building's life.

Using a Boiler Plant would be a viable option for a building like this. The switch to a Natural Gas Boiler Plant has several benefits. First, a commercial Boiler has more than twice the efficiency of delivered electricity. A typical Boiler has an efficiency of about 83%. A typical power plant in the U.S. burns coal at about 40%. After transmission losses, the delivered energy is only about 36%. This inefficiency of the grid leads to much more emissions considering that Natural Gas burns much cleaner than Coal which is in 50% of all U.S. power plants. Secondly, new building construction should be very cautious of relying on the grid's electrical utility rates to remain the same. Deregulation will be taking effect in 2010 and is an almost certainty that electric rates will be raised significantly. On the other hand, Natural gas prices remain quite inexpensive.

9.3 Hydronic System

A hydronic system is a much more efficient heat transfer system than relying on electric resistance and the air system to transfer heat. With the same delta T and same mass flow, water can transport 4 times as much heat. Also, water is 1000 times the density of air. In terms of size, a 1 inch in diameter water pipe could carry the same amount of heat as a 55x55 air duct. This reduction in area usage can dramatically reduce the floor-to-floor height especially with DOAS.

9.4 Schematic



Central Chiller Plant

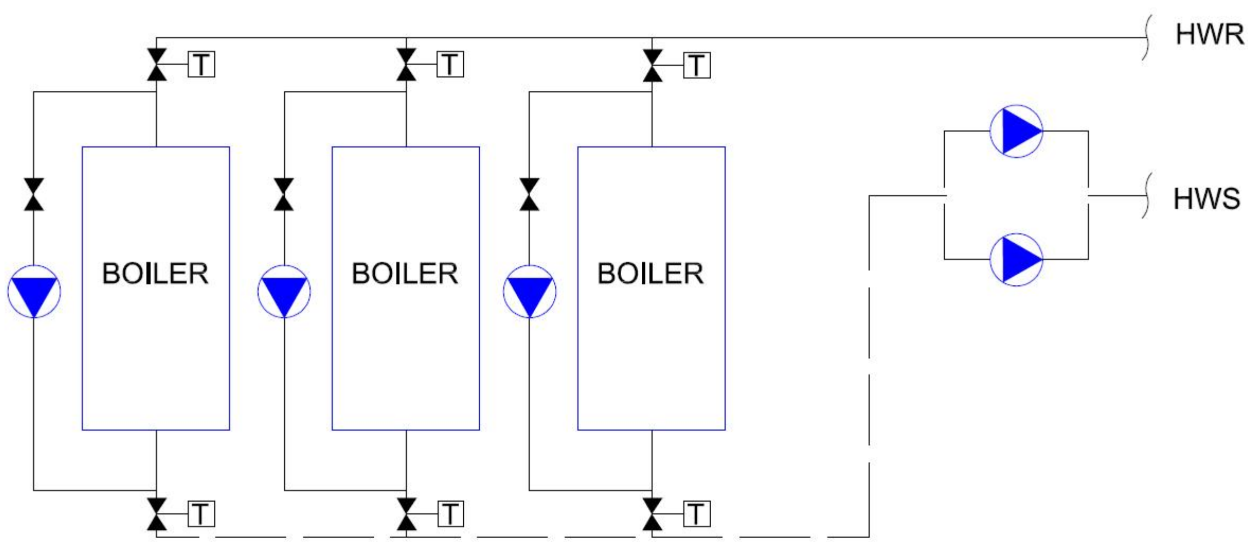


Image 6: Central Boiler Plant

9.5 Energy Use

Since the existing Chiller Plant is quite efficient already and the use of Boiler Plant more than doubles the efficiency of the Heating Plant, the energy usage of the Central Plant should be quite low. Also, in terms of cost/BTU, buying natural gas as opposed to delivered electricity is a much better deal.

9.6 Life Cycle Costs/Maintenance

The following Table compares the Utility Costs for the first 15 years associated with a Central Plant to the Existing Chiller/Electric Resistance. As shown, the Initial Cost of the Central Plant is actually less than the existing system. This is due to the energy reduction from the Dedicated OA System. With the VAV system, the cost would be approximately 20-30% more.

System	kWh $	kW $	Therm $	Total $	Utility $/SF/YR	15 Year Savings $	Initial Cost $	Simple Payback Yrs
Central Plant	5,086,140	382,605	2,836,875	8,305,620	1.51	2,662,545	5,340,000	-0.1
*Existing Plant	9,957,105	1,011,060	-	10,968,165	2.00	-	5,500,000	-

Table 13: 15-Year of Central Plant Utility Costs

A Central Plant typically requires a maintenance cost of around $0.40/SF/YR. This is a typical maintenance cost for a Plant. When compared to the existing Chiller/Electric Resistance Plants, the Central Plant would have a slightly higher maintenance cost due to the upkeep of the Boiler Plant.

9.7 Emissions

One of the main reasons a Central Plant was explore is because of its low energy usage. Westinghouse, as a company, is an industry leader in energy system design. And if their headquarters is not an energy efficient building, then that would only hurt their reputation. Likewise, it would be wise of them to set the standard for other companies and reduce their carbon footprint on the world. A Boiler Plant uses on-site energy as opposed to delivered electrical energy. The use of on-site energy results in less primary fuel used and therefore fewer emissions produces. As discussed previously, natural gas has a quarter of the carbon that coal has. So not only is on-site fuel usage more efficient it is also cleaner.

9.8 Initial Cost

The Initial Cost of the Central Plant was based on figures from previous projects and tabulated numbers from R.S. Means. The Chiller Plant will be similar to the Initial Cost of the Existing Chiller Plant with a cost of about $4,000,000. This number will fluctuate with the three different DOAS configurations with the All Active Chilled Beam layout resulting in the lowest initial cost for the Chiller Plant with $2,530,000.

The Boiler Plant Initial Cost will be much less than the Chiller Plant Initial Cost. The estimated cost for the Boiler Plant is $300/MBH or about $2,000,000. These figures were difficult to find since R.S. Means figures are for the Boiler only and not the piping, pumps, or heating plant accessories.

10.0 Architectural Study

10.1 Existing Design

The existing façade treatments are all designed in basically the same manner. It's fairly safe to assume that all the facades were designed relatively the same for the simple reason of symmetry and it's cheaper and simpler to construct. The symmetry was clearly the defining mark of this building. With a multi-billion dollar company like Westinghouse, a symmetrical hierarchal design definitely well represents the sense of order, permanence, ability, and might that Westinghouse has come to exemplify. However, this emphasis on symmetry and order has somewhat neglected the true purpose of a façade—to protect the building.

The only significant design feature that is a response to the orientation is the horizontal fins on the Cafeteria's large glazing faces. The horizontal fins were placed only on the top half of the glazing leaving the bottom 15 feet or so unprotected. The only reasoning behind this is possibly to give the Cafeteria patrons an unobstructed view of the hill behind the property.

Image 7: Existing Typical Floor Plan

As seen from the Image above, the program of this building called for mostly open office space. Conference rooms are place near the Cores and on the Northeast and Northwest corners. The shaded regions are the Core spaces with restrooms, stairwells, duct shafts, etc.

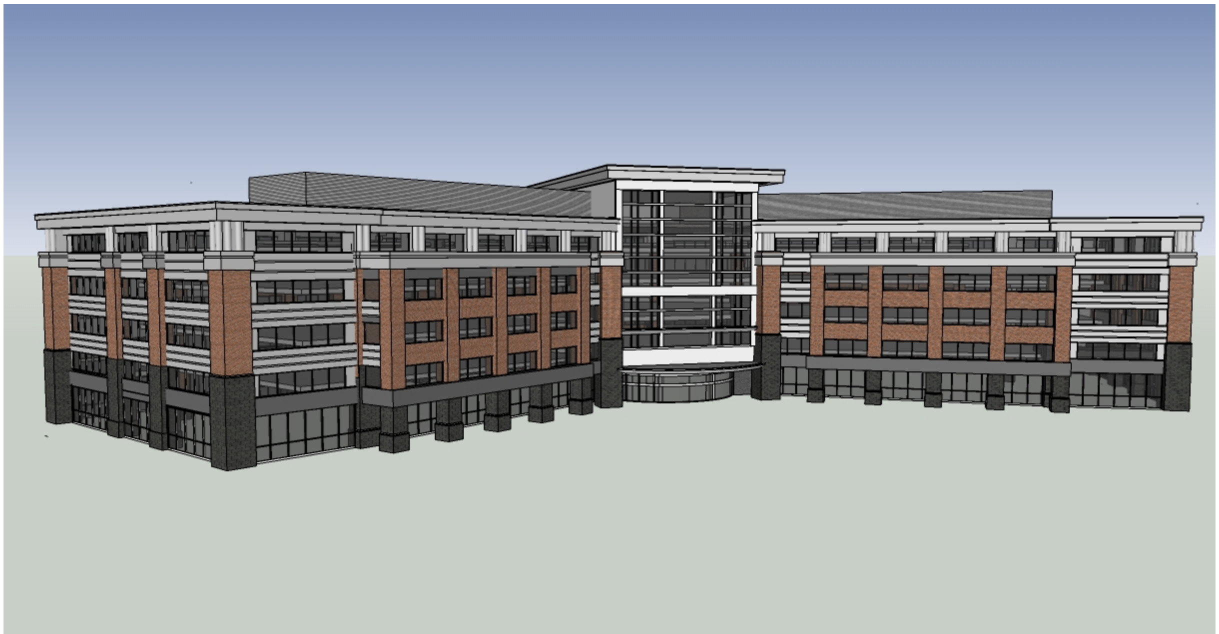


Image 8: Existing North Façade Panorama

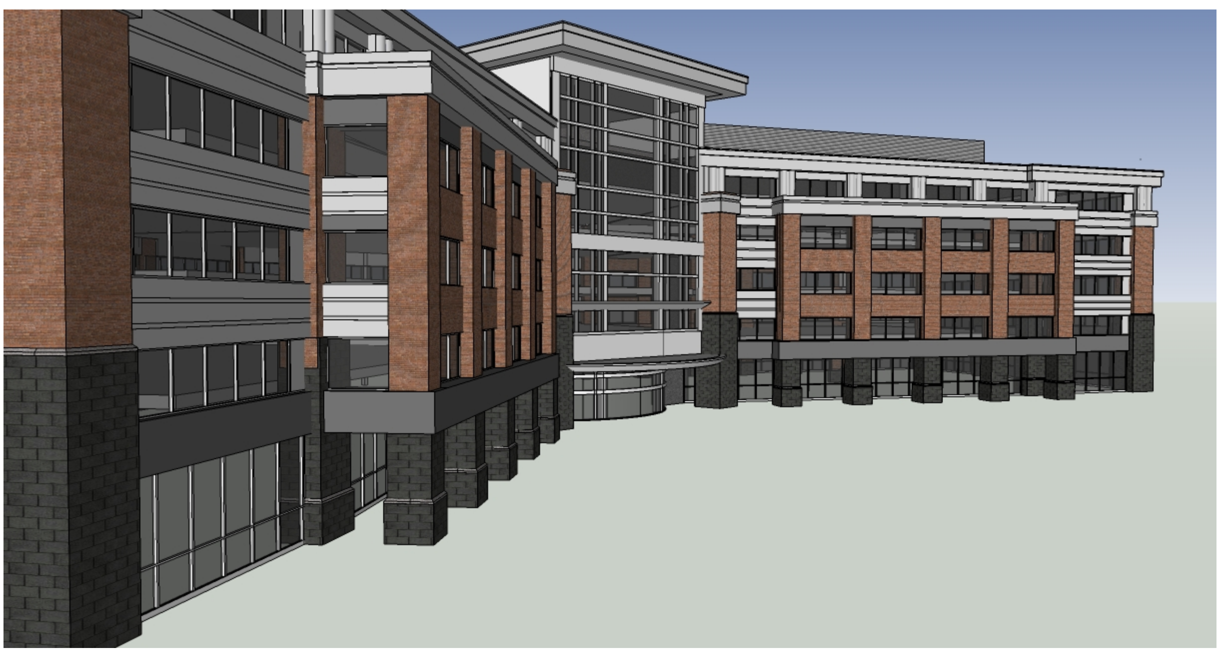


Image 9: Existing North Façade View

The two images above show the symmetry and hierarchy of the building. The brick juts from the wings are used to reinforce this idea of hierarchy and are abutments to the entrance to further signify it.

Image 10: Existing South Façade Panorama

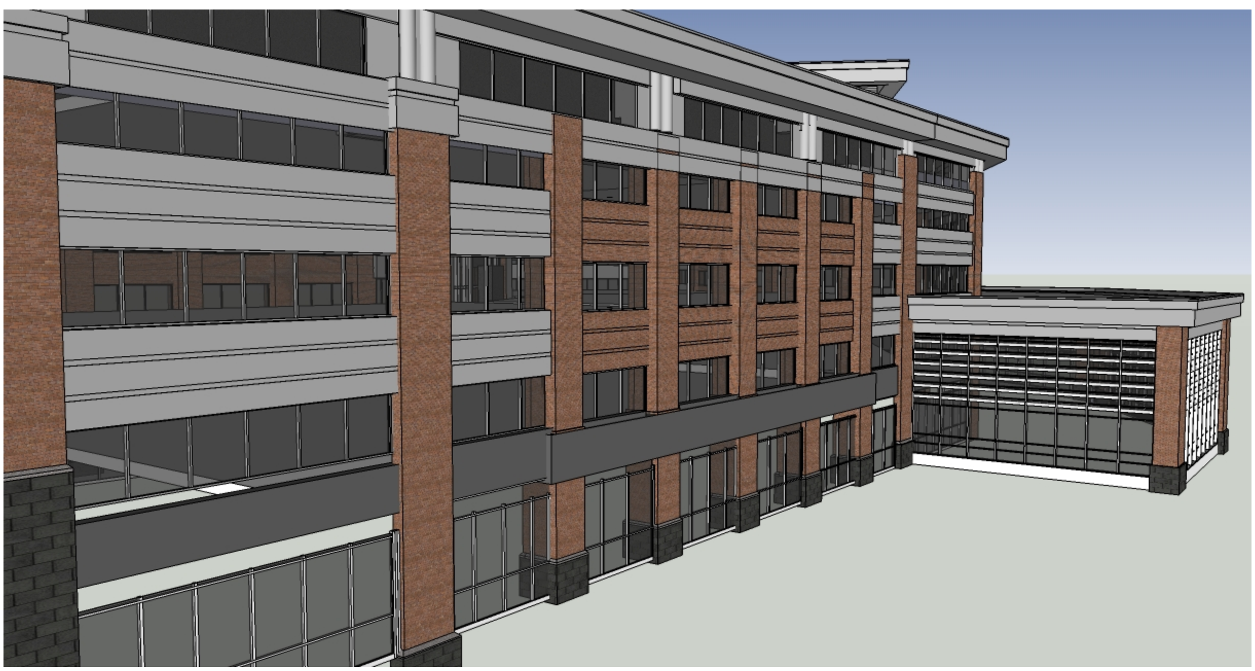


Image 11: Existing South Façade View

The above two images again show the symmetry of the building. Hierarchy was not as enforced on this side of the building because the main entrance is on the north face and no vehicular traffic can really view this side. The Cafeteria’s horizontal fins are seen in these images as well.

10.2 New Design

10.2.1 South Façade

The South façade has clearly the largest thermal loads. Its solar transmission contributes about 65-70% of the total cooling load in the building. To shade the building from the harsh summer sun, solar overhang shades were placed on all the south glazing on floors 2, 3, and 4. These overhangs were designed with two purposes—shade and redirect daylight further into the office space.

An earlier design of these overhangs was to have a solid ban of overhangs going the length of the south façade. However, this idea aesthetically did not complement the rest of the façade since all vertical and horizontal entities on the façade were broken up to reduce the apparent mass of the building. Thus, the overhangs were segmented as well. The overhangs were purposefully designed to appear lighter with its narrow profile and thin tension cable suspension to attempt to ease/compliment the heavy, dark masculinity of the rest of the exterior.

With the East and West facades being so narrow compared to the other two, they did not contribute as much thermal loading. However, for the sake of symmetry and increasing the daylighting in the spaces, the same solar shading treatment was applied to the East and West.

No overhangs were placed on the fifth floor because the large ‘capital’ of the roof overhangs enough to shade during the summer. To save money, the first floor was shaded differently. With the use of deciduous trees, the first floor can be shaded during the summer and shoulder seasons while allowing absorption of winter solar energy. With the cafeteria facing south, this use of heavy shading from trees is most important here. The current cafeteria design has horizontal fins on half of the glazing; however, the cafeteria still has the largest thermal load of any other space in the building. It could also be said that the placement of trees near the building will improve workers' satisfaction of the facility.

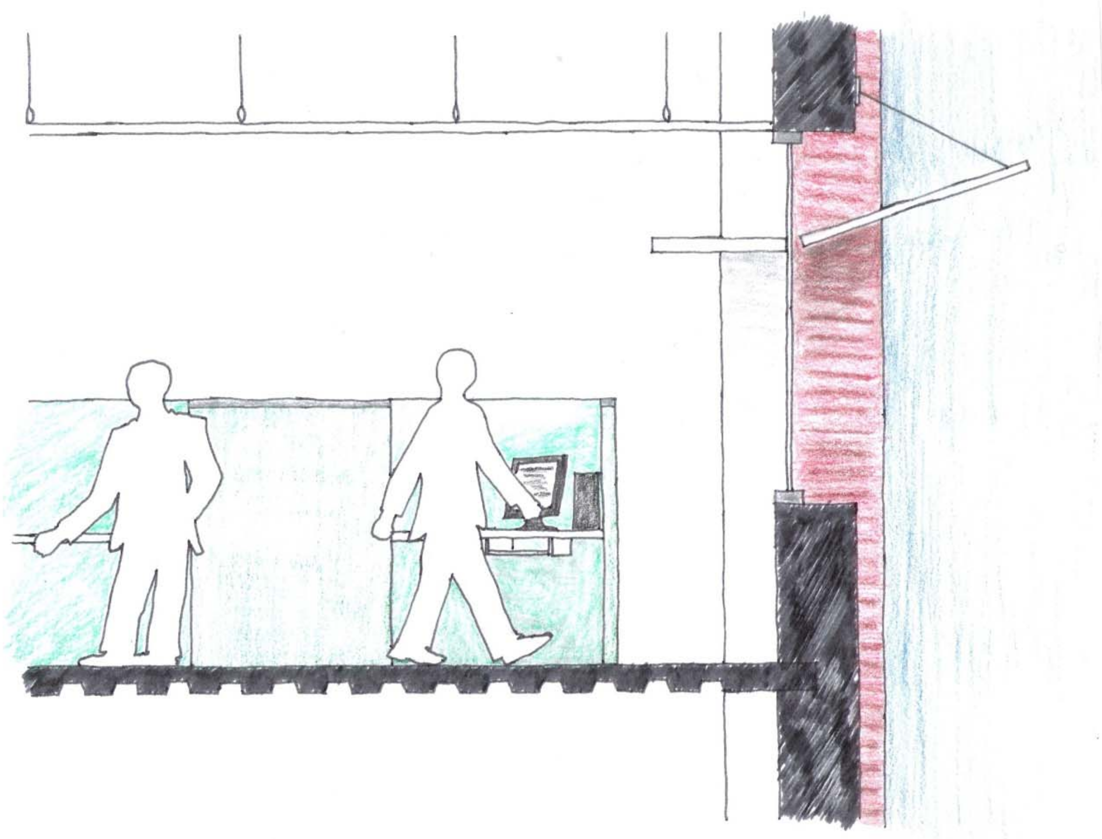


Image 12: New Design South Façade Open Office Section

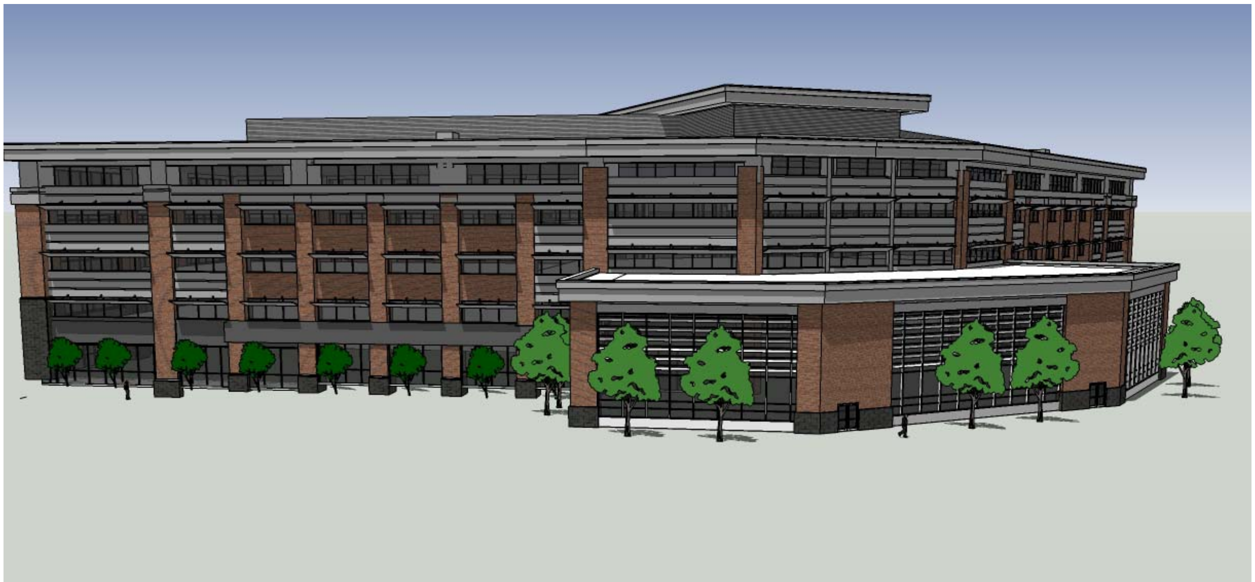


Image 13: New Design South Face Panorama

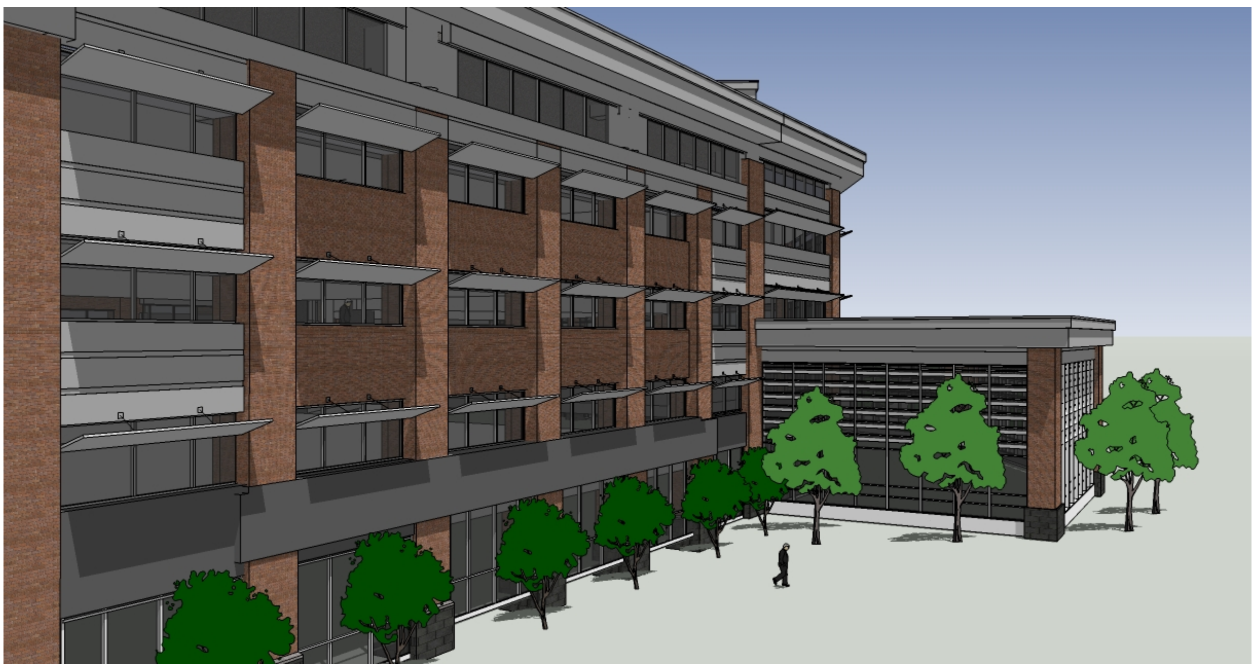


Image 14: New Design South Face View

10.2.2 North Façade

The North façade is whole different story. The major thermal load is heat loss of the glazing during the winter. To combat this loss, two treatments were implemented.

The first was the lowering of the glazing percentage. Lowering the glazing has several downsides—less daylighting, more worker dissatisfaction (feeling of being in a box), and the loss of the sense of transparency of the building. So to be sensitive to this, the selection of where to lower the glazing was done very carefully. The key was a look at the office layout—the corners of the north office area are occupied with conference rooms. Conference rooms generally spend more time unoccupied and when they are occupied it's quite common that PowerPoint presentations are in use. Thus daylighting is not a priority for this space, and the infrequency of their use means that artificial lighting energy use will not be an issue. Hence, thermal loading can be prioritized, and the glazing in these spaces can be dramatically reduced. And with conferences rooms on both ends of the building, the symmetry of the façade is still pronounced.

The second North façade treatment was the implementation of floor to ceiling partitions creating a buffer space on the abutment wings of the 2nd, 3rd, and 4th floors. The current open office layout has an unused space of approximately 5 feet between the cubicles and exterior wall. By adding an all-glass partition, this space can be treated as a separate unoccupied space instead of office space. This means that the temperature in these buffer zones can be allowed to drift higher and lower than the office space.

This design offers many benefits, first of which is that these partitions are moveable and do not hinder the rearrangement of desks, secondly they are all glass so no loss of daylight, and they reduced the heating demand for the north office spaces. The concept still allows these spaces to be accessed with doors at the end of each aisle of cubicles which would allow workers to use the spaces for private calls, etc.

With these façade treatments, the thermal load in the spaces has been drastically reduced and thus the cooling and heating equipment is reduced in size.

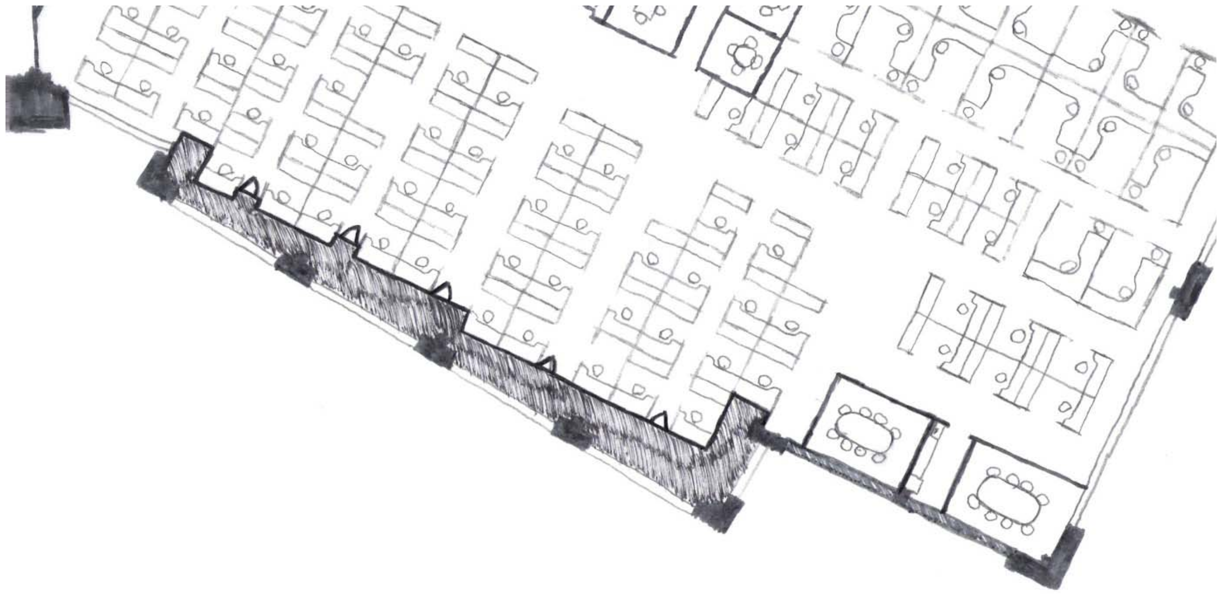


Image 15: New Design North Façade Plan

The shading floor area in the image above is the new Buffer Zone. The conference rooms on the corners had to be rearranged with some of the open office to ensure that no desks would be negatively affected by the lowering of the glazing area.

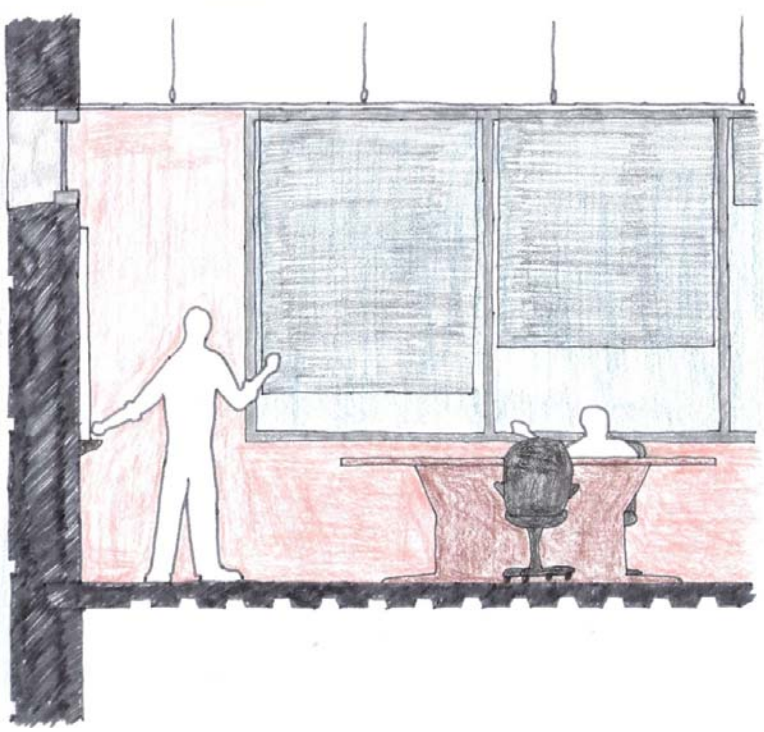


Image 16: New Design North Façade Conference Room Section

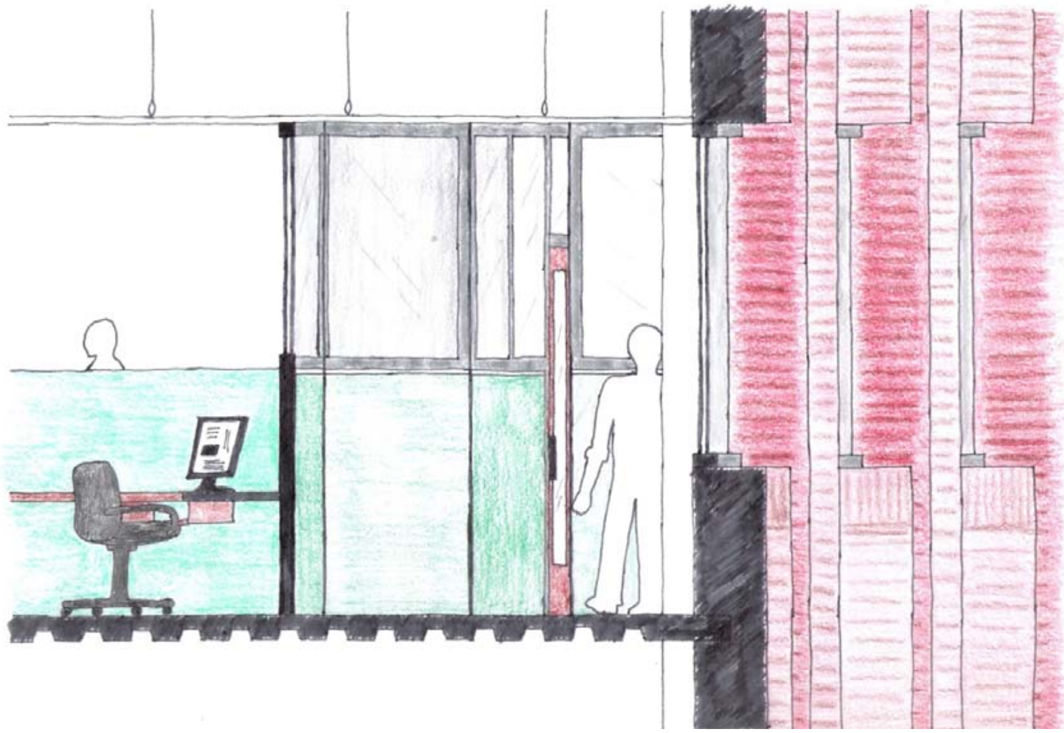


Image 17: New Design North Façade Buffer Zone Section

Image 18: New Design North Façade Panorama

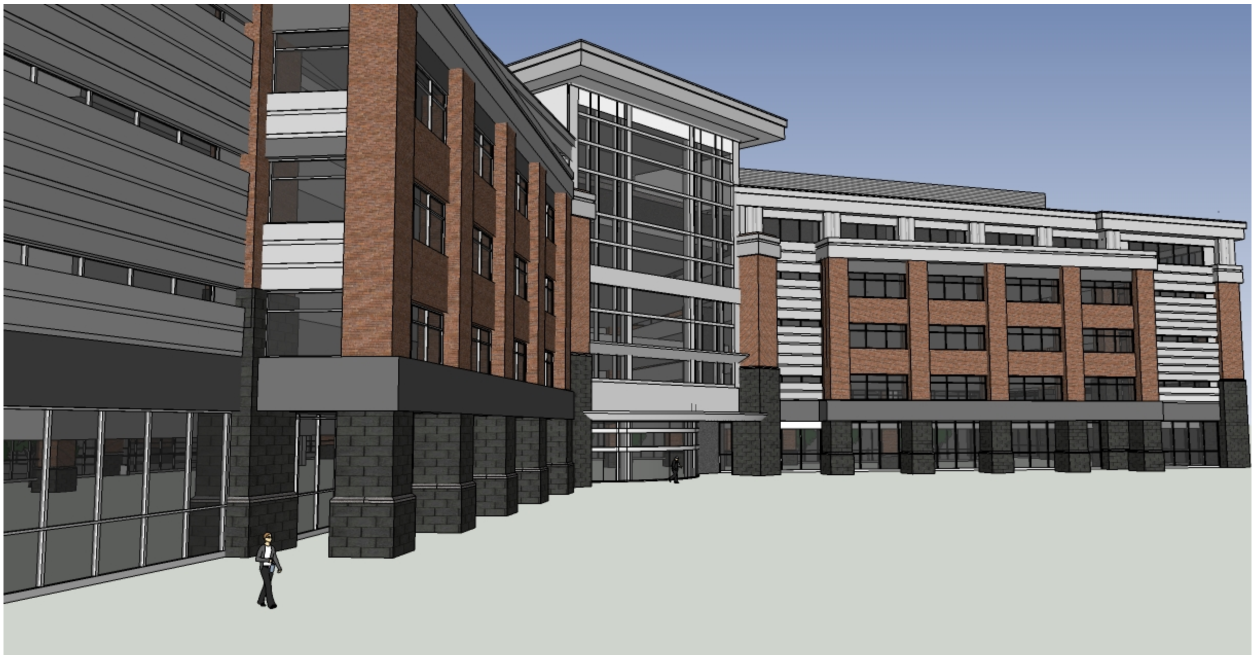


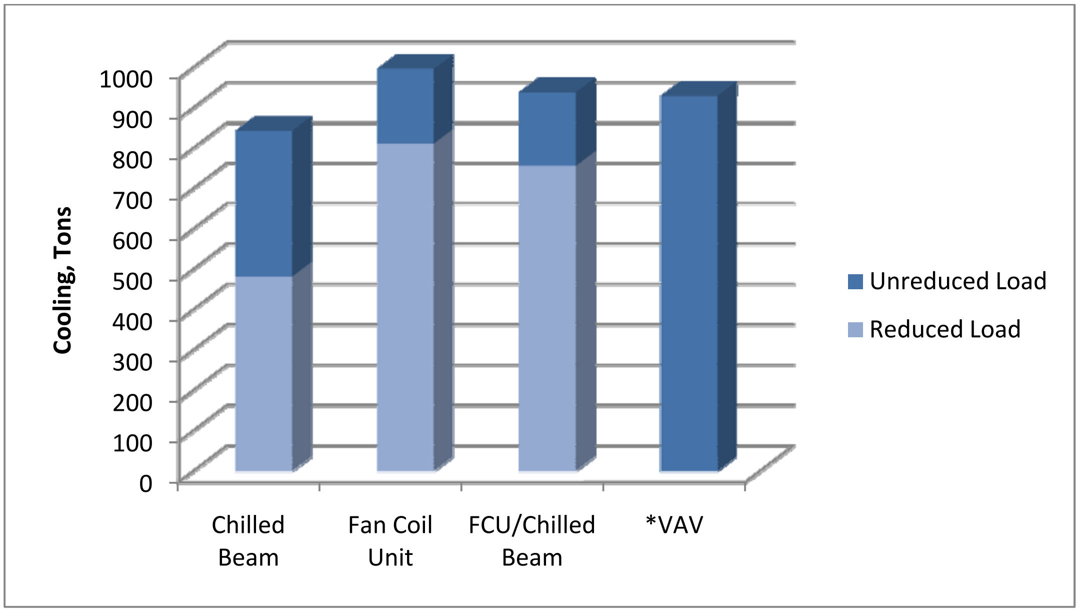
Image 19: New Design North Façade View

As seen from the images above, the lowering of the glazing area did not take away from the architectural style of the façade. With the Conference Room designs, the north glazing was reduced from 40% to 34.5%. In the North Façade View, mullions were added on the abutment wings of the façade to continue the horizontal band pattern and to give continuity to the new scale of the wings.

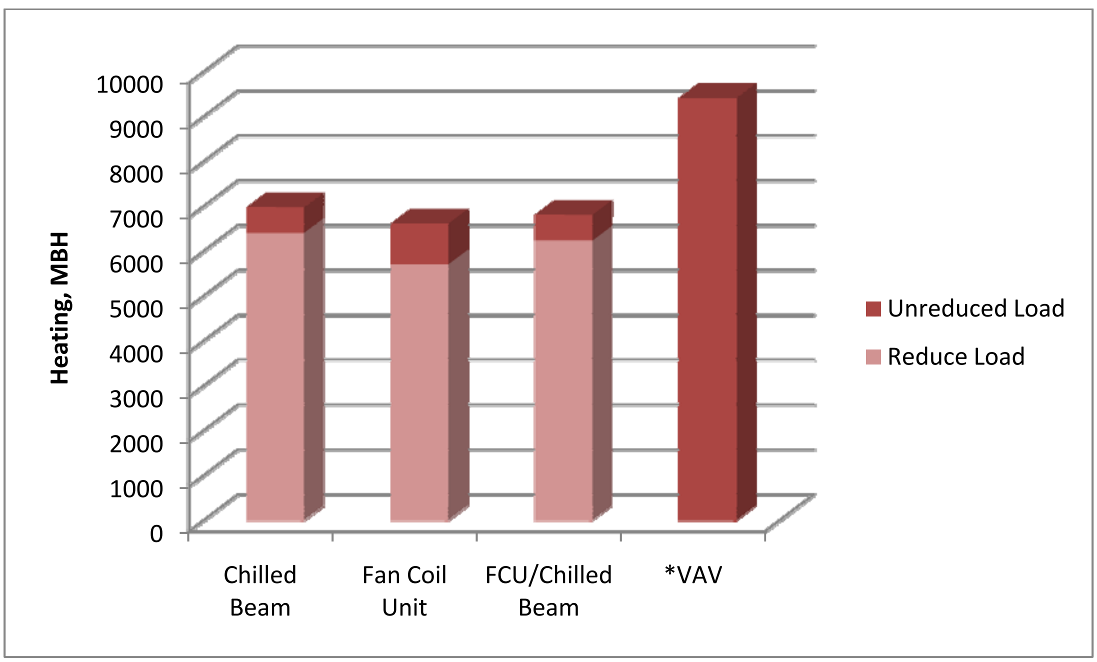
10.3 Effects of Plants

The effects of these architectural designs had a significant impact on the heating and cooling demand on the Mechanical system. The following graphs depict the reduction in the Cooling load and Heating Load respectively. As seen from both graphs, the façade redesigns reduced both the cooling and heating loads. The most notable reduction is the reduced cooling load for the Active Chilled Beams which had a 43% reduction. The other two system layouts also saw reductions of about 20%. The reduction on the Heating Plants was not as significant. All three systems had a heating load reduction of about 12%. This may be attributed to still having 34% glazing on the north face or the buffer zones needed to have larger drift points—they were set to 65 and 78 degrees Fahrenheit.

Impacts on initial cost, energy use, emissions, utility costs will be discussed in the Conclusions section.



Graph 5: Reduced Cooling Load from Façade Re-Design



Graph 6: Reduced Heating Load from Façade Re-Design

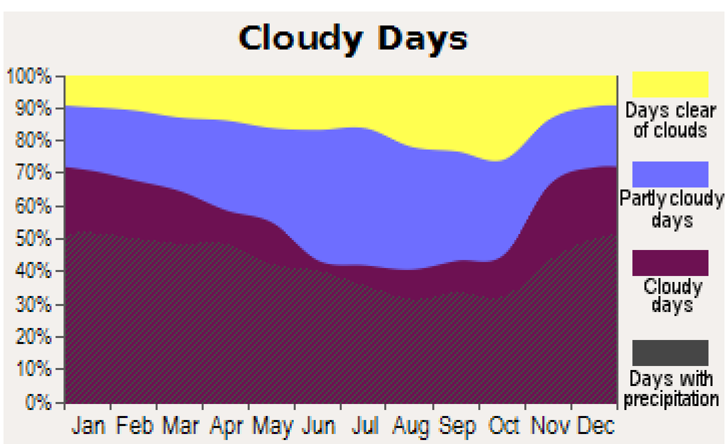
11.0 Daylighting Breadth

11.1 Design

With a Dedicated Outdoor Air System, the CFM delivered is cut down to approximately 20% of the VAV system. This reduction results in the largest ducts going from a 44x14 down to a 24x8. This savings in volume is translated into savings on ceiling height of 6 inches. This increases the ceiling height to 10 feet which will definitely improve the effectiveness of the light shelf design.

With the room height at 10 feet, the light shelves are placed at 8 feet. Eight feet was chosen because it's high enough to not effect office traffic, but low enough to allow a decent sized clerestory.

To effectively block low morning and late afternoon glare, the interior shelf would have to protrude into the space 3.5 feet. 3.5 feet is far too large of a shelf and would possibly be perceived as making the space feel cramped and stuffy. Therefore, the interior shelf was designed to only be 2.5 feet deep. The shorter shelf does not block winter glare, however winter in Pennsylvania is almost always cloudy, thus there should be relatively little glare or complaints. The following graph shows the percentage of clear skies during the winter to only be around 10-15%



Graph 7: Cloud Accumulation for Pittsburgh, PA

The exterior light shelf was designed for two purposes—reflect daylight into the space and shade the glazing from direct solar gain. If daylighting was the only function of the exterior shelf, its length would be about 1.5 times the height of the clerestory or about 3 feet. However, since it serves as a glazing shade, the projection was increased to 4.5 feet. To optimize the exterior shelf's daylighting effectiveness, it was tilted inward at a slope of 18 degrees (Latitude – 22 deg.).

A good measurement of the daylight within a space is the Daylight Factor. Daylight Factors that are between 2-5% make the room appear daylit, but artificial light would be needed. Anything over 5% and no artificial light should be needed.

11.2 Dimmer Control System

In order to take full advantage of the daylighting system, the first two rows of luminaires from the south wall were placed on separate control system. This control system is a Dimmer System which allows a light sensor to actively control the electric lighting within the space to be additive to the daylight within the zone. The Dimmer System allows for energy savings even with daylighting levels below the minimum intensity.

11.3 Results

The following contour plans depict the results of the DaySim Analysis. The Continuous Daylight Autonomy contours are the fraction of time when the lights do not need to be at 100%. The Daylight Autonomy contours are the fraction of time when the lights can be off. The Useful Daylight Illuminance contours are the fraction of time when daylighting light levels are within the acceptance range of 450-1000 footcandles.

According to the results, the light shelves will actually hinder daylighting by a small amount. This was not the expected result for this breadth. However, the results can be explained rather logically. First, the clerestory is only 2 feet in height and is recessed a foot from the façade surface. Having only 2 feet of clerestory really will only marginally increase the daylighting within the space even in a sunny climate. A second disadvantage was the height to depth ratio of the room—10'/45' or about 0.22. With a room this deep, a clear story would have to be nearly 10 feet in height to effectively daylight the whole space.

Even though the light shelves were designed appropriately from this building, it would simply not be worth the expense and implementation to attempt to use daylighting. However, the external shading should definitely still be used as a solar shade (see Architectural Effects on Plant). With this information, the external shade should be relocated at the top of the glazing to gain the full shading effect of the shelf.

The dimmer control of the first two rows of lights, however did have a positive impact. The DaySim results concluded that the dimmer controls would save the building approximately 98,000 kWh/year. Without the dimmer control system, the total energy usage of lights in the building was 819,000 kWh/year, therefore the dimmer control system reduces the usage by 12.0%. This translates to about $10,500/ year in savings.

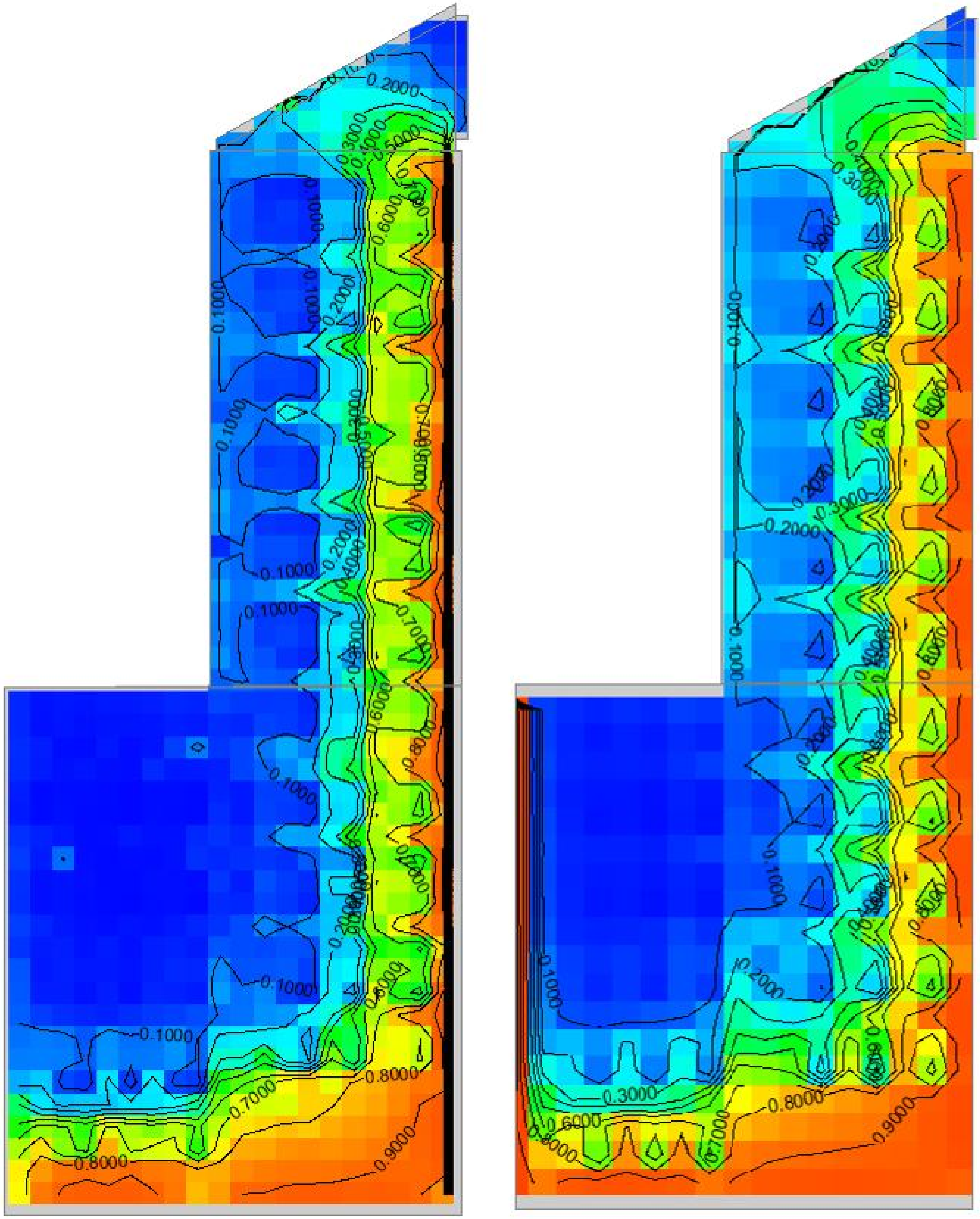


Image 20: Continuous Daylighting Autonomy (left- with light shelves, right- existing)

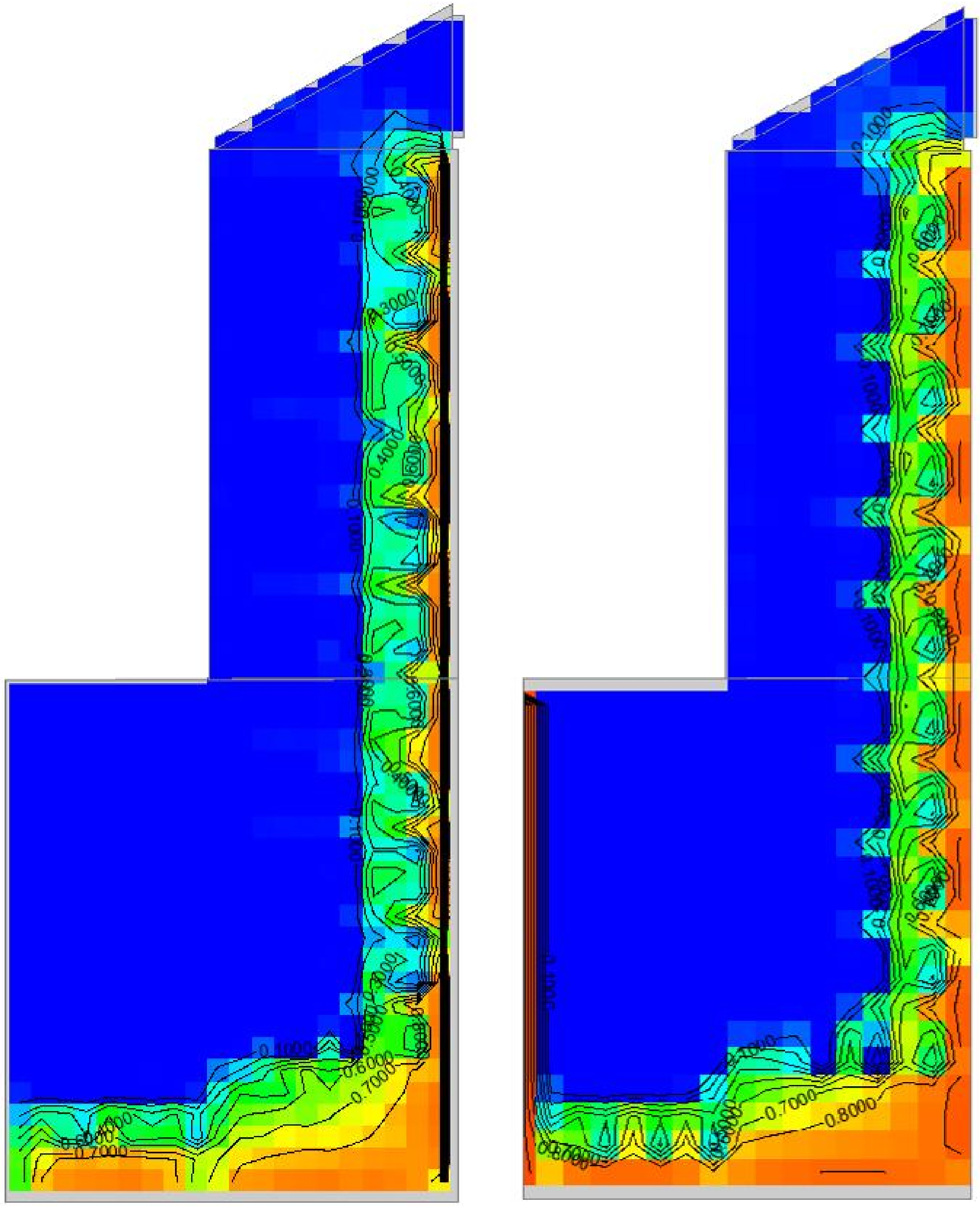


Image 21: Daylighting Autonomy (left- with light shelves, right- existing)

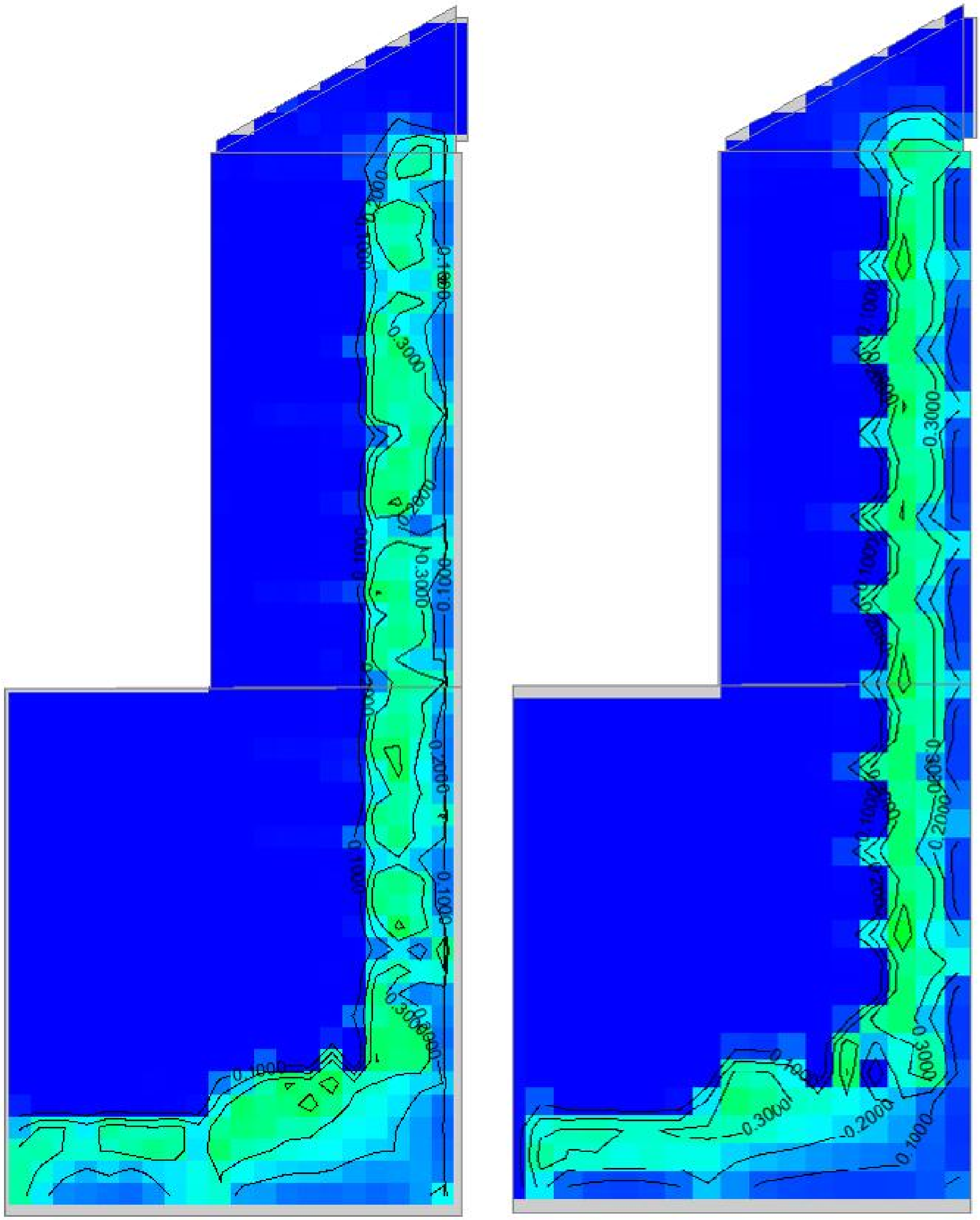


Image 22: Useful Daylight Illuminance (left- with light shelves, right- existing)

11.4 Sections and Plans

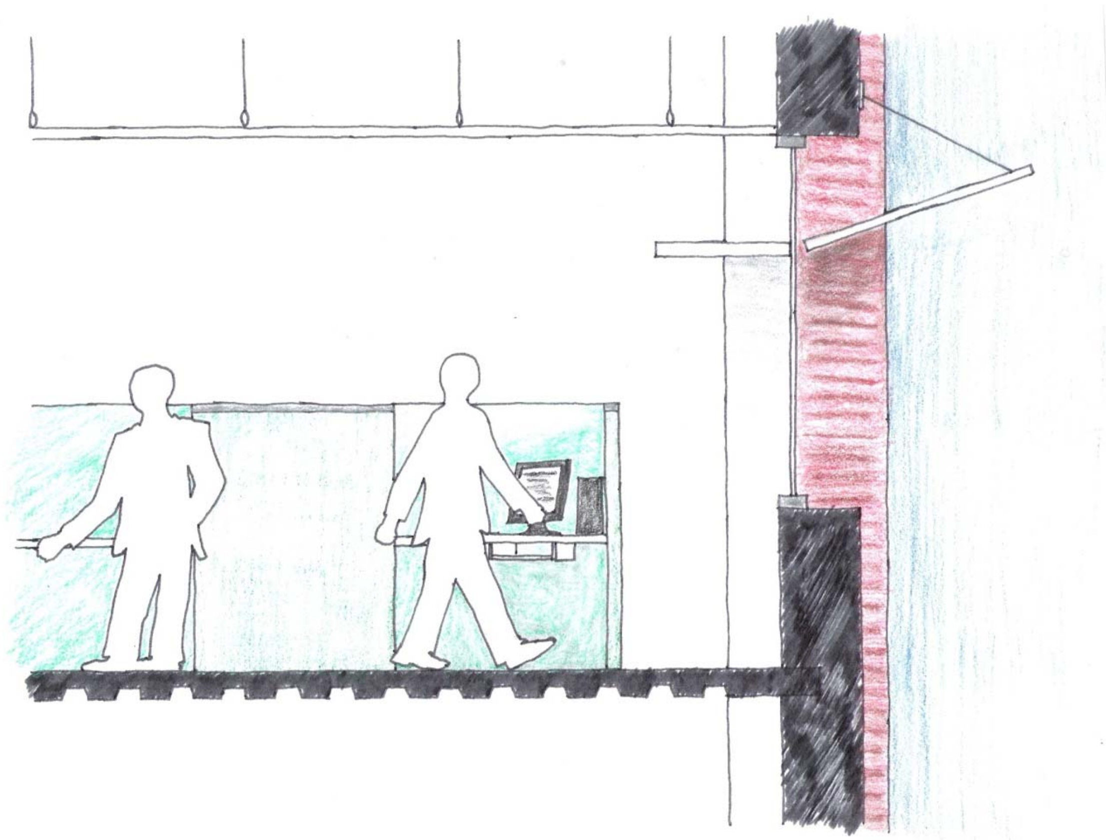
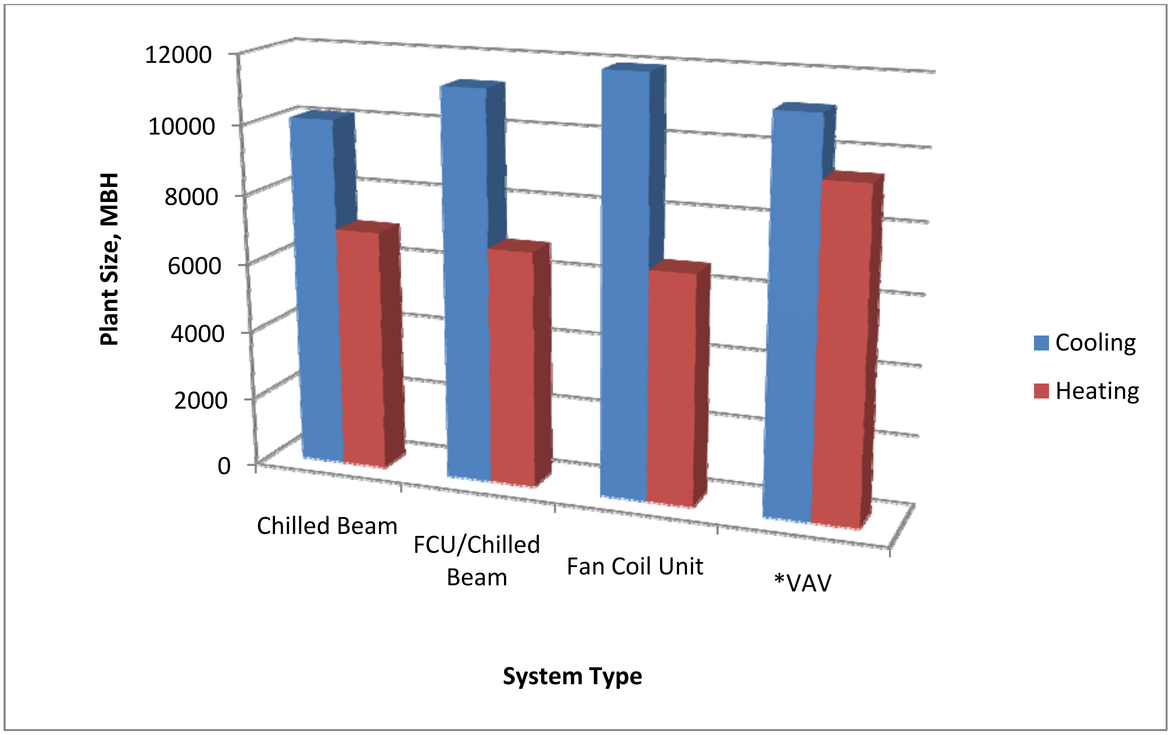


Image 23: Open Office Daylighting Section

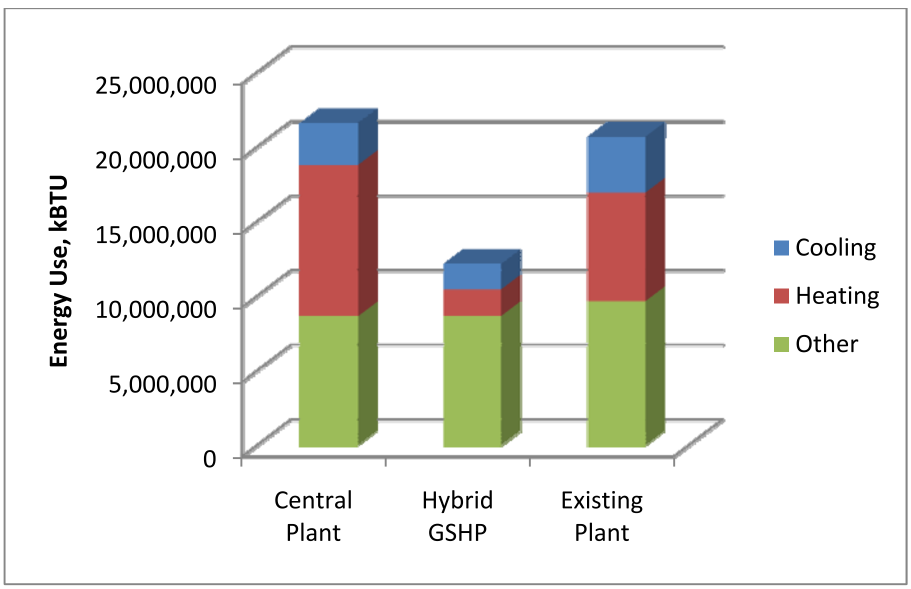
12.0 Conclusions and Discussion of Results

12.1 Energy Use

The following two graphs depict the energy usage associated with each Air System and Plant respectively. As seen, the Active Chilled Beam system requires the smallest Cooling Plant. Likewise, the DOAS Fan Coil Unit system requires the least amount of heating. From this graph it can be seen that it is much more beneficial to use an all Active Chilled Beam layout in terms of lowest total energy usage. The use of the Fan Coil Units only marginally reduces the heating load.

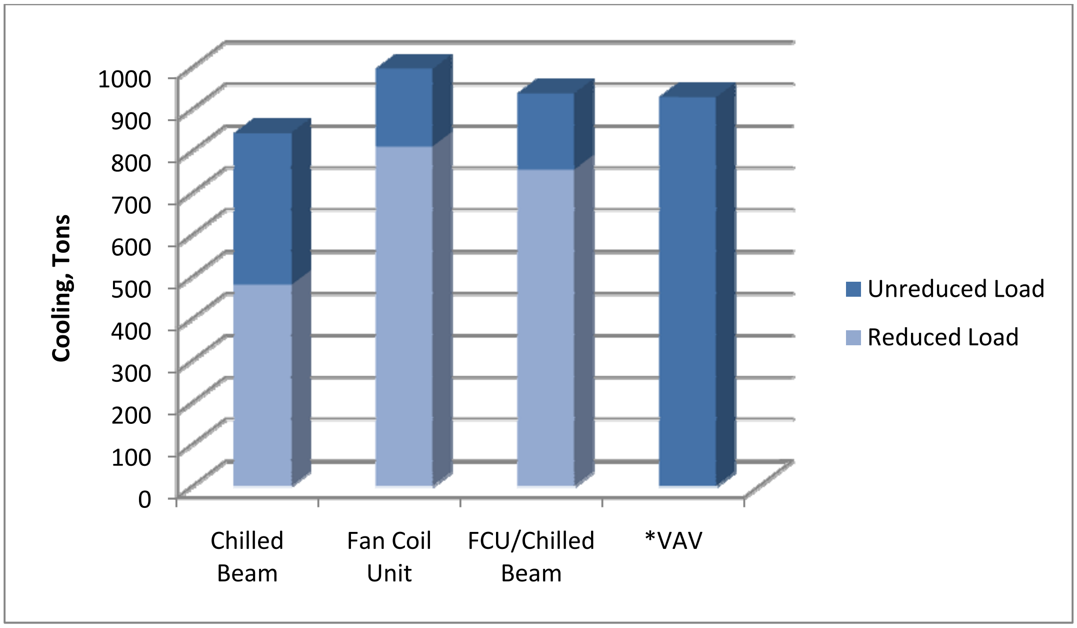


Graph 8: Plant Sizing per Air System

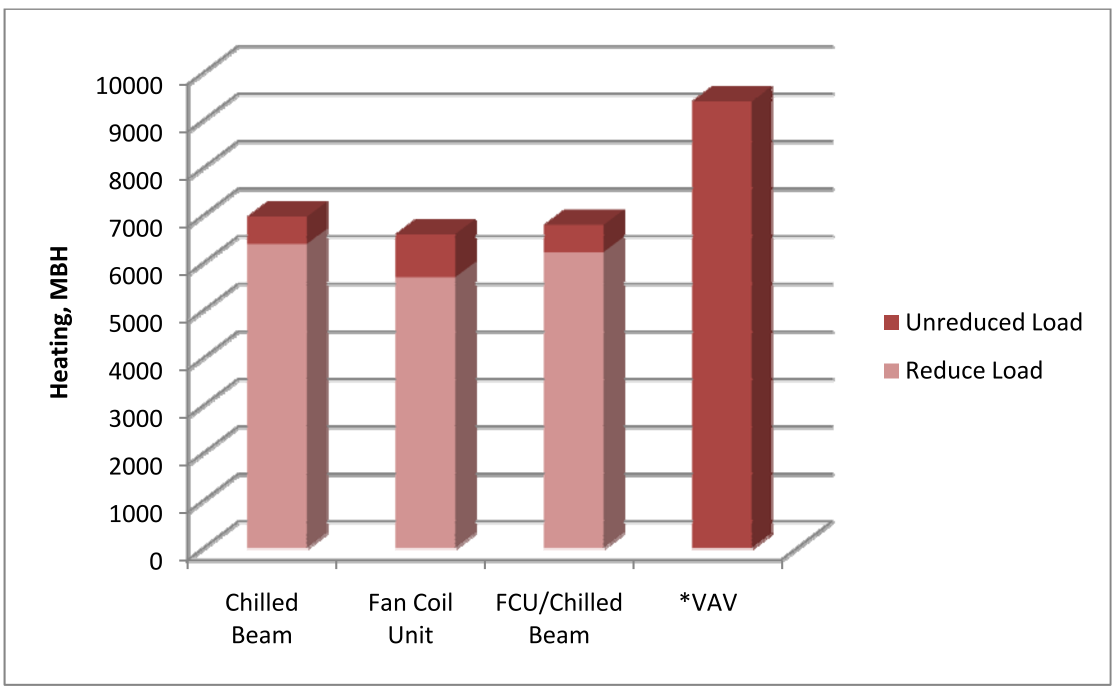


Graph 9: Building Energy Usage per Plant

With the implementation of the Façade Redesign, the plant sizing and energy usage was reduced significantly. The following two graphs show the reduction of the plant sizes. As seen the Active Chilled Beam has the largest cooling reduction while the DOAS Fan Coil Unit has the largest heating reduction.

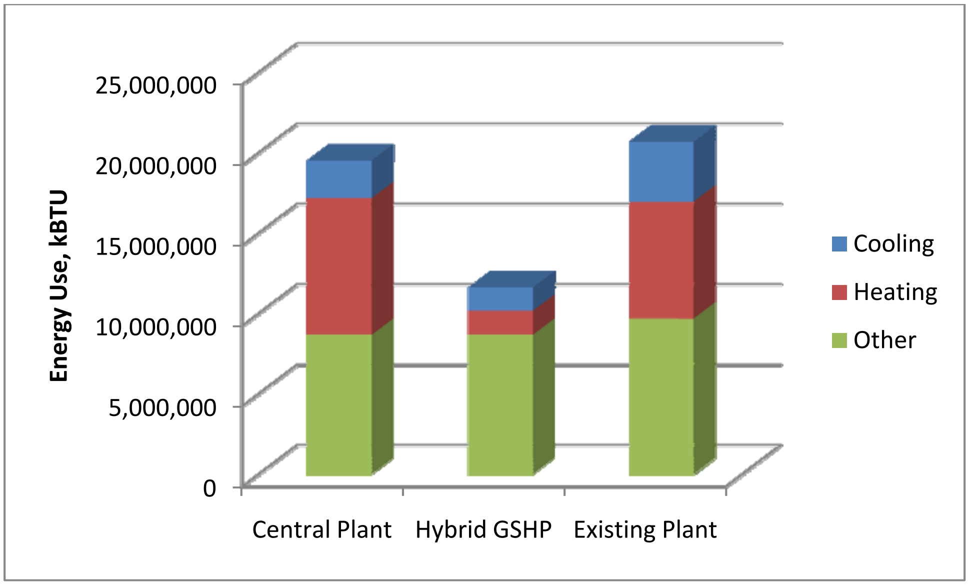


Graph 10: Reduced Cooling Load from Façade Re-Design



Graph 11: Reduced Heating Load from Façade Re-Design

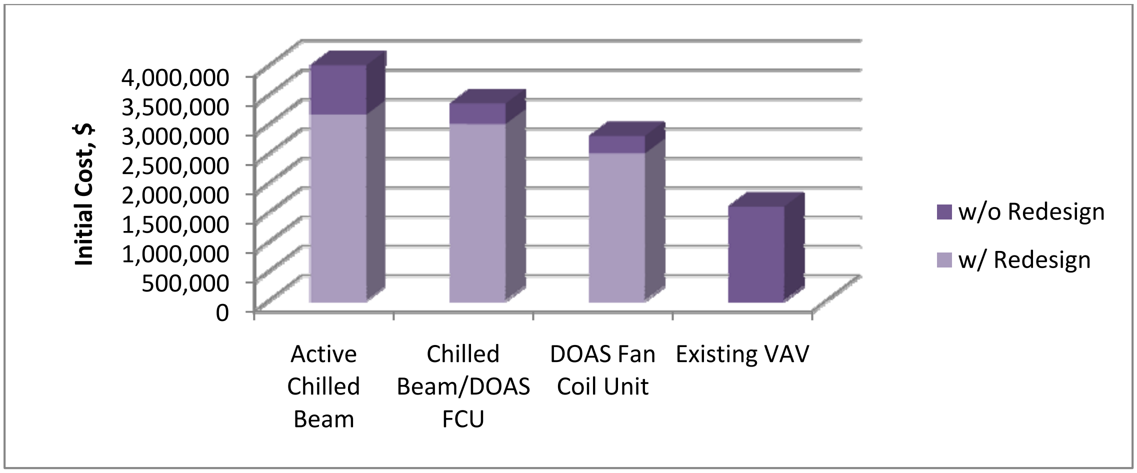
The following graph shows the reduction in the building's energy usage per plant with the façade redesign. As seen from the graph there is a reduction in the heating and cooling energy use. Both Plant designs had a reduction of 16% in both heating and cooling energy use.



Graph 12: Reduced Building Energy Usage per Plant

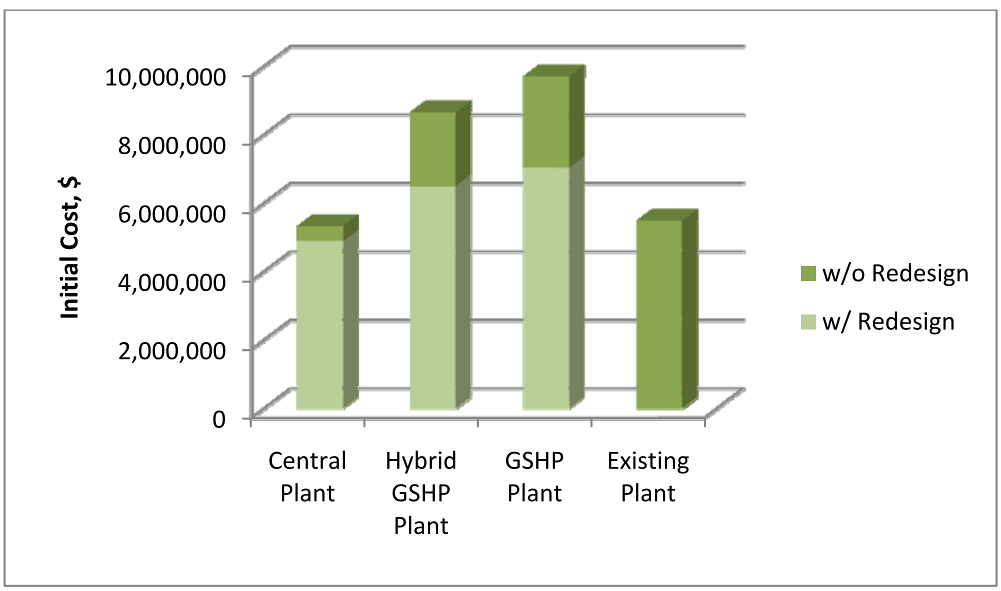
12.2 Initial Cost

The Initial Cost of each of the Air Systems is shown below with and without the Façade Redesign. The Façade Redesign reduces the Initial cost of the ACB system 21% and the other two systems 11%. The Active Chilled Beam System is the most expensive at $3,200,000 with the Façade Redesign. The three designs are significantly higher than the existing air system because of the extra cost of having an Enthalpy Wheel within the DOAS air handling unit. The DOAS air systems would be much higher, but the savings in ductwork and fan sizes reduced the initial cost.



Graph 13: Initial Cost per Air System

The graph below shows the Initial Cost of each Plant both with and without the Façade Redesign. As seen, the most expensive plant would be the All GHSP system, but with the Cooling Tower (Hybrid), the Hybrid GSHP System went down $1,050,000. The Central Plant was found to be actually less than the Existing Plant. This is the result of the load reduction from the Dedicated OA System. Likewise, all three Plants designs would have significantly higher initial costs if they were used in the existing VAV system. The initial cost of these plants in the existing VAV system would increase by about 10-20%.

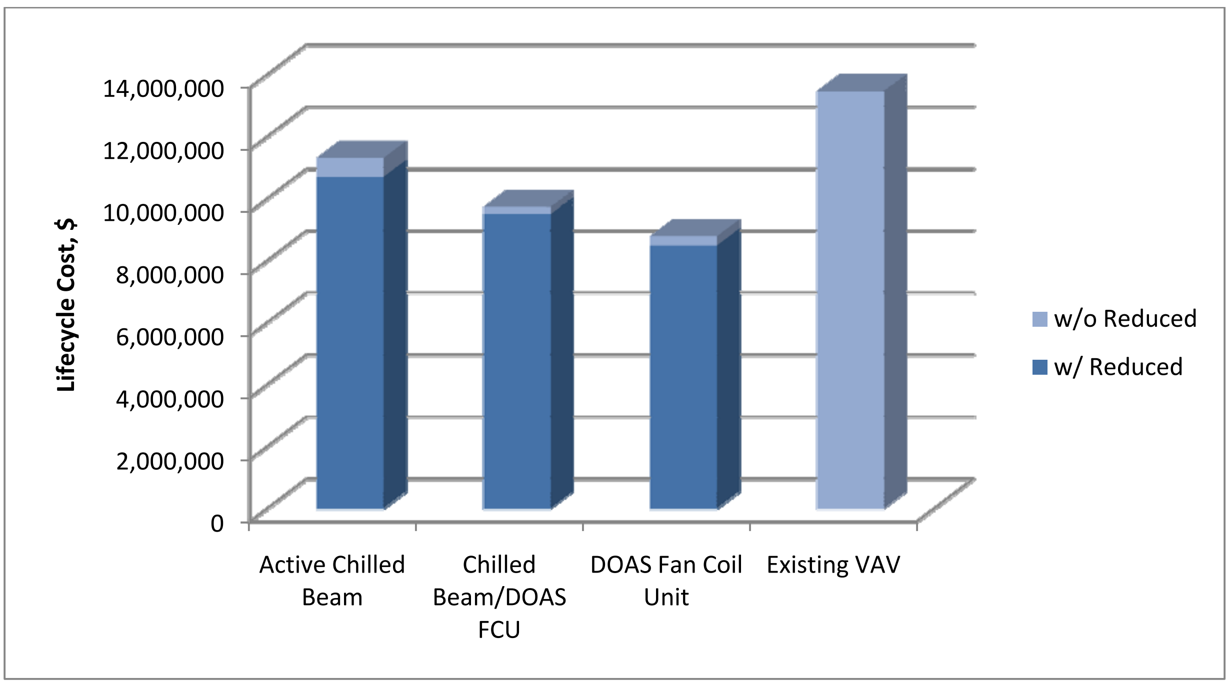


Graph 14: Initial Cost per Plant

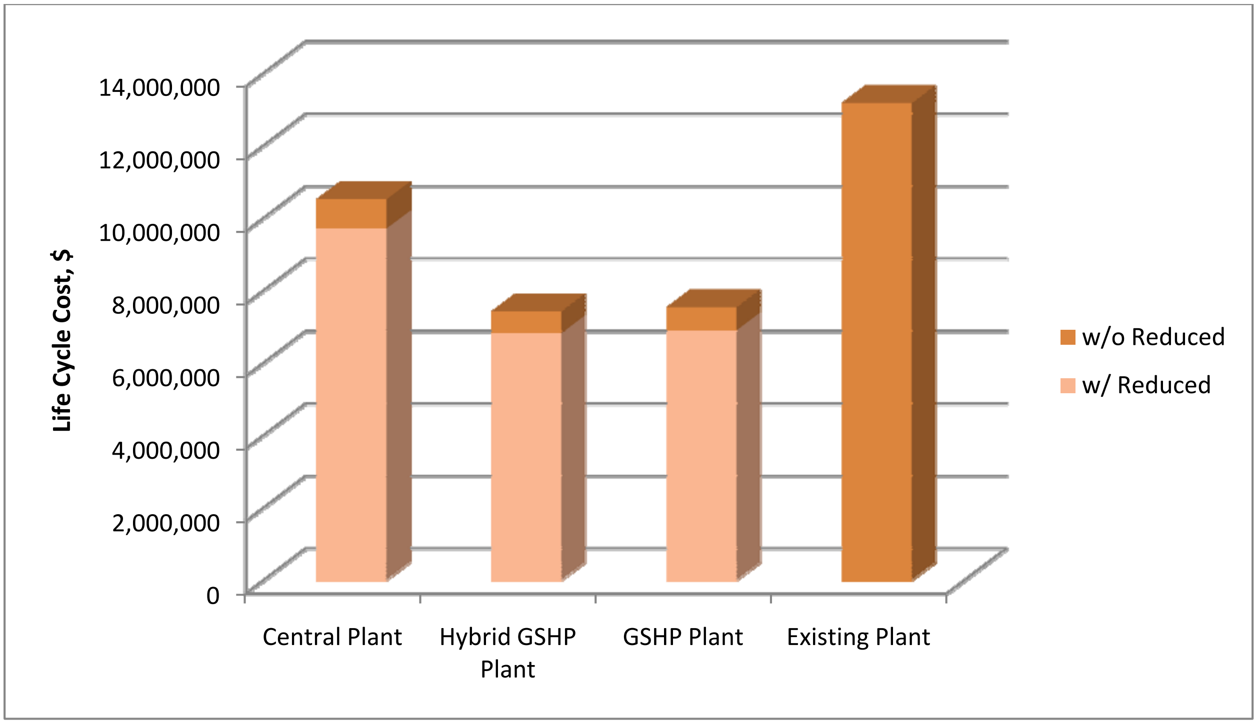
12.3 Annual Utility Cost/ Life Cycle Cost

The 15 Year Lifecycle Costs associated with each air system and Mechanical plant are shown below. Operation Costs were taken from similar buildings. As seen, the Architectural redesign of the façade has little impact on the Life Cycle Cost of the air systems with about a 4% reduction for each system. Overall, the all DOAS FCU air system has the smallest Lifecycles cost among the three designs. This is an interesting result considering that the all Active Chilled Beam uses the least amount of energy.

The Plant graph indicates that the Hybrid Ground Source Heat Pump plant has the smallest Lifecycle Cost over the 15 year period. This is directly related to the low maintenance costs and low energy usage of the GSHP plant.



Graph 15: 15 Year Lifecycle Cost per Air System



Graph 16: 15 Year Lifecycle Cost per Plant

With the information from the Initial Cost and Lifecycle Cost, a simple payback period can be calculated for each air system and plant. The table below shows the payback period for each system and plant combination. This payback period is in comparison to the existing VAV system and Chiller/Electric Resistance plant. As seen from the table, the Central Plant with a DOAS FCU only System will have the shortest payback of about 0.9 years. With the Façade Redesign, the payback period for each combination is reduced dramatically by about 60% for the GSHP Plants and about 80% for the Central Plant.

Simple Payback Period (Years)	Without Façade Redesign			With Façade Redesign		
	ACB only	ACB/FCU	FCU only	ACB only	ACB/FCU	FCU only
GSHP Plant	21.3	18.9	18.3	8.4	8.9	7.1
Hybrid GSHP Plant	18.0	15.6	13.4	5.4	7.2	5.5
Central Plant	12.6	9.6	5.6	2.7	2.4	0.9

Table 14: Simple Payback Period per System/Plant Combination

12.4 Indoor Air Quality

Indoor Air Quality is a difficult air characteristic to quantify, but a very important one to consider. The Active Chilled Beam system would have a best IAQ over the DOAS FCU and the existing VAV system. This is because the only air supplied to the space is outdoor air which means that there is no chance for a decrease when the load in the space decreases.

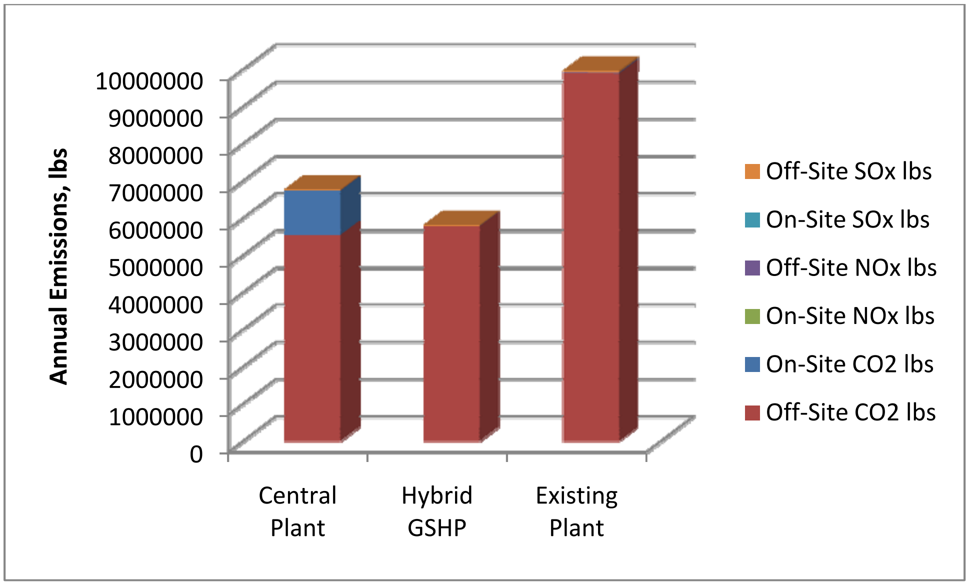
With the DOAS FCU, although the ventilation air is 100% outdoor air, the Terminal Unit uses its air dampers to control the conditioning of the space. The chance of the dampers being not set properly is still a threat to the Indoor Air Quality. Thus, if all the DOAS FCUs have their dampers properly set, the IAQ of the DOAS FCUs will be equivalent to the Active Chilled Beam.

This is not the case for the existing VAV system. Similarly to the DOAS FCU, the dampers will adjust when the space load fluctuates to adequately condition the space. And like the DOAS FCU, the existing VAV unit dampers may be incorrectly set and could inadequately supply enough ventilation air. However, unlike the DOAS FCU, the existing air system mixes return air with the ventilation air which lowers the IAQ of the building by re-circulating possible contaminates.

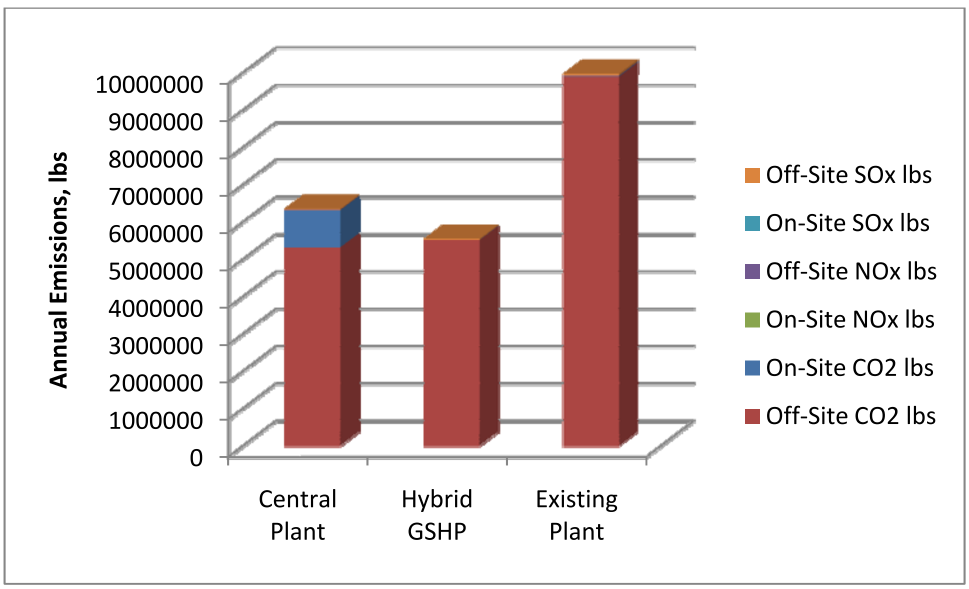
Therefore, in terms of Indoor Air Quality an Active Chilled Beam system would be the preferred system selection. If Active Chilled Beams are not possible, a Dedicated OA System Fan Coil Unit could provide similar IAQ to the Active Chilled Beam but would need closer maintenance.

12.5 Environmental Impact

The following graphs show the emissions related to each Plant. The second graph shows the emissions with the new façade design. As seen from both graphs, the existing plant creates much more emissions than either new plant. This is due to the VAV system in the existing building and the existing mechanical plant's reliance on delivered electricity. Switching to a Central Plant is equivalent to taking 316 cars off the road and switching to a Hybrid GSHP Plant is equivalent to 386 cars. With the Façade Redesign, the emissions is reduces slightly by about 6% or an extra 30 cars.



Graph 17: Emissions per Plant without Façade Redesign



Graph 18: Emissions per Plant with Façade Redesign

12.6 Operation and Maintenance

The Dedicated Outdoor Air Unit needed a standard amount of maintenance as does any air handling unit. The Enthalpy Wheel in the unit typically needs to be replaced every 20 years or so with good maintenance. The replacement of the wheel adds about $500,000 on to the 15 year Lifecycle Cost.

The Active Chilled Beams are a very good system in terms of maintenance. ACBs do not have any moving parts, thus regular inspection is not needed. This low maintenance also leads to long lives as well. Most maintenance costs with an Active Chilled Beam system will come from the mechanical plant or the air handling unit.

The DOAS Fan Coil Units have relatively the same amount of maintenance needed as a conventional VAV unit. The biggest maintenance to the system will be the replacement of the filters on the units. Since the DOAS FCU has a fan in the unit, the life span will be lower than the Active Chilled Beam unit.

The Ground Source Heat Pump Plant will need minimal maintenance. Additionally, the life span of the ground loop is in the vicinity of 50 years and the Heat Pump's life span is around 25 years. However, GSHPs are not as common in the United States, thus the maintenance staff will have to be trained for operating the equipment.

A Central Plant would have a nominal amount of maintenance required. A Central chiller and boiler plant are very common in commercial buildings today and maintenance staff should be able to operate it with relative ease. The chiller plant should have a life span of about 20 to 30 years. The boiler plant has an estimated life of about 20 years.

12.7 Construction Impact

Even though this project is being delivered as a Design-Bid-Build, the construction impact can definitely effect the decision of an owner as to what system they want. The best air system for a construction standpoint is the existing VAV system, with the all

DOAS FCU second, the ACB/DOAS FCU layout third, and the all ACB last. The Active Chilled Beams would require a specialized contractor to install them.

For the plants, the existing Chiller/Electric Resistance would have the least impact on the construction since there is no heating plant to install. Second would be the Central Plant, third would be the Hybrid GSHP Plant and last would be the non-Hybrid GSHP Plant. The Hybrid plant would require less bores drilled thus less time spent. Also, drilling of the bores in the middle of the parking lot area will delay the paving as well as hinder construction site traffic.

12.8 Conclusions

After completing multiple analyses, the best mechanical plant for this application is the Hybrid Ground Source Heat Pump Plant. While the Central Plant had the shortest Payback Period, the other criteria for a successful plant swayed more toward the Hybrid GSHP. However, A Central Plant would probably be the choice of the Owner. The Initial Cost would be the biggest factor in terms of their decision. They are leasing this building to Westinghouse, so their biggest priority is a return on their investment.

From the standpoint of Westinghouse, I would suggest the Hybrid GSHP Plant. Westinghouse is the United States most prominent company for the energy industry. They would be poorly marketing themselves if they did not opt for the more efficient plant. The Hybrid GSHP Plant uses the least amount of energy, has the lowest Lifecycle Cost, and produces the least amount of emissions. These facts would be very beneficial for the marketing of Westinghouse.

The best air system for the Westinghouse Headquarters is the all Dedicated Outdoor Air System Fan Coil Unit layout. From the Owner's standpoint, they would again elect for the least expensive Initial Cost in the existing VAV system. However, when considering the benefits that come with DOAS e.g. smaller plant size, smaller lifecycle cost, smaller operation and maintenance costs, and the huge benefit of improve indoor air quality, it would be absurd not to consider DOAS. Several studies have been done on a comparison to a 100% OA ventilation to a conventional 30% OA ventilation. The results were a dramatic increase in worker productivity and fewer sick days.

Thus, from this analysis the best option is the Hybrid Ground Source Heat Pump Plant combined with the all DOAS Fan Coil Unit System. The following tables are summaries of the comparisons for the air systems and mechanical plants.

1- Best, 4- Worst	Air Systems			
	ACB only	ACB/FCU	FCU only	Existing VAV
Plant Size	1	2	3	4
Initial Cost	4	3	2	1
Life Cycle	3	2	1	4
Payback Period	2	3	1	-
IAQ	1	2	3	4
Op. and Maint.	1	2	3	4
Construction	4	3	2	1
Average Value	**2.3**	**2.4**	**2.1**	**3.0**

Table 15: Summary of Comparison of Air System Options

1- Best, 4- Worst	Mechanical Plant			
	Hybrid GSHP	GSHP	Central Plant	Existing Plant
Energy Use	1	2	3	4
Initial Cost	3	4	1	2
Life Cycle Cost	1	2	3	4
Payback Period	2	3	1	-
Environmental Impact	1	2	3	4
Op. and Maint.	2	3	1	4
Construction	3	4	2	1
Average Value	**1.9**	**2.9**	**2.0**	**3.2**

Table 16: Summary of Comparison of Plant Options

References

1. Int-Hout, Chief Engineer, Dan. “A Reasonable Alternative to Chilled Beams- The DOAS Fan Powered Terminal Unit.”May 2009. Krueger HVAC. 8 Dec. 2009

   <http://doas.psu.edu>

This article discusses the benefits of a DOAS Fan Powered Box over the popular Chilled Beam. The article explains the uses of each terminal unit and how they can work in tandem.

2. Kavanaugh, PhD, Steve. “Ground Source Heat Pumps.” ASHRAE Journal 40.10 (1998): 31-36.

This article discusses in some detail the cost of a GSHP system for different construction methods and tubing used. It also includes design suggestions, potential outputs for various GSHP systems. The article illustrates its point with a thorough example of a GSHP in a small commercial building.

3. Kavanaugh, PhD, Steve. “Ground Source Heat Pumps for Commercial Buildings.” September 2008. HPAC Engineering. 8 Dec. 2009

   <http:///hpac.com>

This web article discusses some of the key points of how a Ground Source Heat Pump System operates. It compares a GSHP system to other standard commercial systems. Additionally, it lists the benefits and disadvantages of three different types of GSHP.

4. Minea, PhD, Vasile. “Ground Source Heat Pumps.” ASHRAE Journal 48 (2006): 28-35.

This article discusses a comparison of a vertical to a horizontal Ground Source Heat Pump System in Canadian Schools. The article includes discussions on system descriptions, construction costs, soil temperatures, energy consumption and operating experiences.

5. Mumma, PhD, PE, Stanley. “Dedicated Outdoor Air Systems.”February 2001. The Pennsylvania State University DOAS. 14 Dec. 2009

<http://doas.psu.edu>

This webpage discusses the advantages of a Dedicated OA System over a conventional system—namely VAV. It also explains the basic concept of how DOAS is implemented into a building.

6. Mumma, PhD, PE, Stanley. “Designing Dedicated Outdoor Air Systems.”ASHRAE Journal 43.5 (2001): 28-31.

This article discusses in some detail the working parameters of DOAS. The article includes a comparison of a VAV system to three different configurations of DOAS.

7. Rafferty, PE, Kevin. “A Capital Cost Comparison of Commercial Ground-Source Heat Pump Systems.” Geo-Heat Center, Oregon Institute of Technology.

Appendix A: Trane Trace Results

System Checksums

By PENN STATE UNIVERSITY

Main System — Parallel Fan Powered VAV, Htg Coil on Mixing Box Outlet

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

CLG SPACE PEAK — Mo/Hr: 9 / 12; OADB: 73

	Cooling Coil Peak: Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Clg Space Peak: Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	53,330	53,330	0	0	0
Glass Solar	3,568,087	0	3,568,087	32	5,176,271	72
Glass/Door Cond	359,316	0	359,316	3	-181,781	-3
Wall Cond	270,352	451,903	722,256	6	217,212	3
Partition/Door	315		315	0	7,294	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	590,347		590,347	5	49,367	1
Sub Total ==>	4,788,418	505,234	5,293,651	47	5,268,363	73
Internal Loads						
Lights	145,970	583,880	729,850	7	152,093	2
People	2,104,188	0	2,104,188	19	1,097,766	15
Misc	567,814	0	567,814	5	587,978	8
Sub Total ==>	2,817,971	583,880	3,401,851	31	1,837,836	25
Ceiling Load	97,311	-97,311	0	0	82,680	1
Ventilation Load	0	0	2,316,983	21	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	26,595	0
Exhaust Heat		-71,596	-71,596	-1		
Sup. Fan Heat			205,642	2		
Ret. Fan Heat		3	3	0		
Duct Heat Pkup		-462,997	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	7,703,700	457,212	11,146,534	100.00	7,217,474	100.00

HEATING COIL PEAK — Mo/Hr: Heating Design; OADB: 5

	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	-129,452	1.76
Glass Solar	0	0	0.00
Glass/Door Cond	-2,383,476	-2,383,476	32.33
Wall Cond	-381,292	-1,022,116	13.86
Partition/Door	-209,586	-209,586	2.84
Floor	-19,001	-19,001	0.26
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	16.26
Sub Total ==>	-4,191,930	-4,962,206	67.31
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-2.42
Sub Total ==>	178,595	178,595	-2.42
Ceiling Load	-212,180	0	0.00
Ventilation Load	0	0	0.00
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		0	0.00
OA Preheat Diff.		-2,588,523	35.11
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-4,225,515	-7,372,134	100.00

TEMPERATURES

	Cooling	Heating
SADB	56.4	83.8
Ra Plenum	72.9	66.1
Return	72.8	66.1
Ret/OA	74.5	66.1
Fn MtrTD	0.0	0.0
Fn BldTD	0.1	0.0
Fn Frict	0.3	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	433,771	263,277
Terminal	433,771	263,277
Main Fan	433,771	130,131
Sec Fan	0	133,145
Nom Vent	54,007	0
AHU Vent	54,007	0
Infil	17,824	17,824
MinStop/Rh	130,131	130,131
Return	451,596	147,955
Exhaust	71,831	351
Rm Exh	0	0
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	13.6	0.0
cfm/ft²	1.22	0.37
cfm/ton	466.98	
ft²/ton	383.34	
Btu/hr·ft²	31.30	-26.42
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	928.9	11,146.5	8,484.9	433,771	74.7	61.6	64.8	55.0	52.6	58.0
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	928.9	11,146.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	93,535	45,032	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-6,527.5	263,277	60.6	83.8
Aux Htg	0.0	0	0.0	0.0
Preheat	-2,880.4	54,007	5.0	55.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-9,407.8			

The Existing System Checksum (Cooling 928.9 Tons, Heating 9,407.9 MBH)

System Checksums

By PENN STATE UNIVERSITY

Main System — **Active Chilled Beams**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 9 / 12; Outside Air: OADB/WB/HR: 73 / 61 / 62

Clg Space Peak — Mo/Hr: 11 / 12; OADB: 54

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	-12,165	-12,165	0	0	0
Glass Solar	3,812,379	0	3,812,379	84	4,351,275	85
Glass/Door Cond	-5,717	0	-5,717	0	-666,664	-13
Wall Cond	183,147	311,731	494,877	11	98,917	2
Partition/Door	-38,910		-38,910	-1	-95,238	-2
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	43,283		43,283	1	-334,838	-7
Sub Total ==>	3,994,182	299,566	4,293,747	94	3,353,452	66
Internal Loads						
Lights	156,863	627,451	784,314	17	156,863	3
People	1,939,581	0	1,939,581	43	1,063,340	21
Misc	599,069	0	599,069	13	599,069	12
Sub Total ==>	2,695,513	627,451	3,322,964	73	1,819,272	36
Ceiling Load	209,232	-209,232	0	0	147,195	3
Ventilation Load	-1,143,659	0	-1,143,659	-25	-205,830	-4
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			579,899	13		
Ov/Undr Sizing	-2,266,144		-2,266,144	-50	0	0
Exhaust Heat		-226,133	-226,133	-5		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	3,489,125	491,652	4,560,676	100.00	5,114,089	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-128,674	1.32
Glass Solar	0	0	0.00
Glass/Door Cond	-2,383,476	-2,383,476	24.40
Wall Cond	-381,292	-1,018,267	10.42
Partition/Door	-209,586	-209,586	2.15
Floor	-19,001	-19,001	0.19
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	12.27
Sub Total ==>	-4,191,930	-4,957,579	50.74
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-1.83
Sub Total ==>	178,595	178,595	-1.83
Ceiling Load	-253,605	0	0.00
Ventilation Load	-1,406,296	-1,406,296	14.39
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		240,290	-2.46
OA Preheat Diff.		-2,062,722	21.11
RA Preheat Diff.		0	0.00
Additional Reheat		-1,762,599	18.04
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-5,673,238	-9,770,310	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	72.0
Ra Plenum	73.9	65.8
Return	73.9	65.8
Ret/OA	73.9	65.8
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	30,416	113,252
Terminal	30,416	113,252
Main Fan	30,416	113,252
Sec Fan	0	0
Nom Vent	96,419	82,345
AHU Vent	96,419	82,345
Infil	17,824	17,824
MinStop/Rh	113,252	113,252
Return	144,659	213,421
Exhaust	114,243	100,169
Rm Exh	0	0
Auxiliary	658,379	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	317.0	72.7
cfm/ft²	0.09	0.32
cfm/ton	99.96	
ft²/ton	1,170.43	
Btu/hr-ft²	10.25	-12.81
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Aux Clg	380.1	4,560.7	4,560.7	658,379	72.0	59.9	61.2	65.5	57.5	61.2
Opt Vent	304.2	3,650.7	1,892.3	96,419	71.5	65.1	86.8	53.1	52.4	60.0
Total	684.3	8,211.4								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	93,535	45,032	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-2,500.2	113,252	51.3	72.0
Aux Htg	-4,377.6	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Reheat	-2,500.2	113,252	51.3	72.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-2,062.7	96,419	50.0	70.0
Total	-8,940.5			

Central Plant w/ All ACB (Cooling 684.3 Tons, Heating 8,940.5 MBH)

System Checksums

By PENN STATE UNIVERSITY

Main System — **Active Chilled Beams**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 9 / 12; Outside Air: OADB/WB/HR: 73 / 61 / 62

Clg Space Peak — Mo/Hr: 11 / 12; OADB: 54

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	-12,626	-12,626	0	0	0
Glass Solar	3,812,379	0	3,812,379	59	4,351,275	85
Glass/Door Cond	-5,717	0	-5,717	0	-666,664	-13
Wall Cond	183,147	312,779	495,926	8	98,917	2
Partition/Door	-38,910		-38,910	-1	-95,238	-2
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	159,240		159,240	2	-334,836	-7
Sub Total ==>	4,110,139	300,153	4,410,293	69	3,353,452	65
Internal Loads						
Lights	156,863	627,451	784,314	12	156,863	3
People	1,939,581	0	1,939,581	30	1,063,340	21
Misc	599,069	0	599,069	9	599,069	12
Sub Total ==>	2,695,513	627,451	3,322,964	52	1,819,272	35
Ceiling Load	233,770	-233,770	0	0	166,994	3
Ventilation Load	-1,050,408	0	-1,050,408	-16	-207,895	-4
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	-1,166		-1,166	0	-1,166	0
Exhaust Heat		-254,791	-254,791	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		-80,333	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	5,987,849	358,711	6,426,894	100.00	5,130,658	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-126,704	1.55
Glass Solar	0	0	0.00
Glass/Door Cond	-2,383,476	-2,383,476	28.76
Wall Cond	-381,292	-1,018,413	12.29
Partition/Door	-209,586	-209,586	2.53
Floor	-19,001	-19,001	0.23
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	14.46
Sub Total ==>	-4,191,930	-4,957,755	59.82
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-2.16
Sub Total ==>	178,595	178,595	-2.16
Ceiling Load	-252,030	0	0.00
Ventilation Load	-1,422,826	-1,422,827	17.17
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-244,102	-244,102	2.95
Exhaust Heat		241,103	-2.91
OA Preheat Diff.		-2,082,351	25.13
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-5,932,293	-8,287,336	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	70.0
Ra Plenum	74.1	65.8
Return	74.1	65.8
Ret/OA	74.1	65.8
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	87,788	114,353
Terminal	87,788	114,353
Main Fan	87,788	114,353
Sec Fan	0	0
Nom Vent	97,387	83,313
AHU Vent	97,387	83,313
Infil	17,824	17,824
MinStop/Rh	0	0
Return	202,998	215,490
Exhaust	115,211	101,137
Rm Exh	0	0
Auxiliary	664,700	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	110.9	72.9
cfm/ft²	0.25	0.32
cfm/ton	191.22	
ft²/ton	775.59	
Btu/hr-ft²	15.47	-7.30
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	151.8	1,821.9	229.4	75,262	74.1	60.6	61.2	54.0	52.0	57.0
Aux Clg	383.8	4,605.0	4,605.0	664,700	72.0	59.9	61.2	65.5	57.5	61.2
Opt Vent	307.3	3,687.4	1,911.3	97,387	71.5	65.1	86.8	53.1	52.4	60.0
Total	842.9	10,114.3								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	93,535	45,032	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-516.7	114,353	65.8	70.0
Aux Htg	-4,375.6	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-2,082.4	97,387	50.0	70.0
Total	-6,974.6			

Hybrid GSHP Plant w/ All ACB (Cooling 842.9 Tons, Heating 8,940.5 MBH)

System Checksums

By PENN STATE UNIVERSITY

Main System — 4-pipe Induction

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

Clg Space Peak — Mo/Hr: 7 / 15; OADB: 86

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	69,105	69,105	1	0	0
Glass Solar	2,791,252	0	2,791,252	42	2,182,626	51
Glass/Door Cond	426,838	0	426,838	6	481,181	11
Wall Cond	263,761	415,692	679,454	10	235,258	5
Partition/Door	20,278		20,278	0	25,612	1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	602,298		602,298	9	226,794	5
Sub Total ==>	4,104,426	484,797	4,589,223	69	3,151,471	73
Internal Loads						
Lights	139,357	557,426	696,783	10	133,951	3
People	1,762,929	0	1,762,929	26	913,631	21
Misc	556,018	0	556,018	8	553,438	13
Sub Total ==>	2,458,304	557,426	3,015,730	45	1,601,021	37
Ceiling Load	349,862	-349,862	0	0	353,206	8
Ventilation Load	-860,276	0	-860,276	-13	-944,716	-22
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	157,547		157,547	2	157,547	4
Exhaust Heat		-231,848	-231,848	-3		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		-52,918	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	6,209,863	407,597	6,670,377	100.00	4,318,528	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-126,461	1.95
Glass Solar	0	0	0.00
Glass/Door Cond	-2,383,476	-2,383,476	36.77
Wall Cond	-381,292	-1,007,311	15.54
Partition/Door	-209,586	-209,586	3.23
Floor	-19,001	-19,001	0.29
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	18.49
Sub Total ==>	-4,191,930	-4,944,409	76.27
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-2.75
Sub Total ==>	178,595	178,595	-2.75
Ceiling Load	-371,505	0	0.00
Ventilation Load	-700,145	-700,144	10.80
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	3	3	0.00
Exhaust Heat		206,705	-3.19
OA Preheat Diff.		-1,223,605	18.87
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-5,084,981	-6,482,854	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	124.6
Ra Plenum	75.1	64.7
Return	75.1	64.7
Ret/OA	75.3	64.7
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	49,577	49,577
Terminal	49,577	49,577
Main Fan	49,577	49,577
Sec Fan	0	0
Nom Vent	55,071	40,997
AHU Vent	55,071	40,997
Infil	17,824	17,824
MinStop/Rh	0	0
Return	122,472	108,398
Exhaust	72,895	58,821
Rm Exh	0	0
Auxiliary	389,250	389,250
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	111.1	82.7
cfm/ft²	0.14	0.14
cfm/ton	155.50	
ft²/ton	1,116.87	
Btu/hr·ft²	10.74	-12.33
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	127.4	1,528.4	1,125.6	49,577	75.1	61.0	61.2	54.0	49.8	48.9
Aux Clg	677.6	8,131.1	6,920.9	389,250	72.0	59.9	61.2	55.2	52.4	56.9
Opt Vent	191.5	2,297.4	1,265.9	55,071	74.6	66.2	87.5	53.1	52.3	60.0
Total	996.4	11,956.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	93,535	45,032	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-3,167.6	49,577	64.7	124.6
Aux Htg	-2,219.2	389,250	68.0	73.3
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-1,223.6	55,071	49.2	70.0
Total	-6,610.3			

Central Plant w/ All DOAS FCU (Cooling 996.4 Tons, Heating 6,610.3 MBH)

System Checksums

By PENN STATE UNIVERSITY

Main System — 4-pipe Induction

COOLING COIL PEAK / CLG SPACE PEAK

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

CLG SPACE PEAK — Mo/Hr: 7 / 15; OADB: 86

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	69,105	69,105	1	0	0
Glass Solar	2,791,252	0	2,791,252	42	2,182,626	51
Glass/Door Cond	426,838	0	426,838	6	481,181	11
Wall Cond	263,761	415,692	679,454	10	235,258	5
Partition/Door	20,278		20,278	0	25,612	1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	602,298		602,298	9	226,794	5
Sub Total ==>	4,104,426	484,797	4,589,223	69	3,151,471	73
Internal Loads						
Lights	139,357	557,426	696,783	10	133,951	3
People	1,762,929	0	1,762,929	26	913,631	21
Misc	556,018	0	556,018	8	553,438	13
Sub Total ==>	2,458,304	557,426	3,015,730	45	1,601,021	37
Ceiling Load	349,862	-349,862	0	0	353,206	8
Ventilation Load	-860,276	0	-860,276	-13	-944,716	-22
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	157,547		157,547	2	157,547	4
Exhaust Heat		-231,848	-231,848	-3		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		-52,918	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	6,209,863	407,597	6,670,377	100.00	4,318,528	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-126,461	1.95
Glass Solar	0	0	0.00
Glass/Door Cond	-2,383,476	-2,383,476	36.77
Wall Cond	-381,292	-1,007,311	15.54
Partition/Door	-209,586	-209,586	3.23
Floor	-19,001	-19,001	0.29
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	18.49
Sub Total ==>	-4,191,930	-4,944,409	76.27
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-2.75
Sub Total ==>	178,595	178,595	-2.75
Ceiling Load	-371,505	0	0.00
Ventilation Load	-700,145	-700,144	10.80
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	3	3	0.00
Exhaust Heat		206,705	-3.19
OA Preheat Diff.		-1,223,605	18.87
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-5,064,981	-6,482,854	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	124.6
Ra Plenum	75.1	64.7
Return	75.1	64.7
Ret/OA	75.3	64.7
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	49,577	49,577
Terminal	49,577	49,577
Main Fan	49,577	49,577
Sec Fan	0	0
Nom Vent	55,071	40,997
AHU Vent	55,071	40,997
Infil	17,824	17,824
MinStop/Rh	0	0
Return	122,472	108,398
Exhaust	72,895	58,821
Rm Exh	0	0
Auxiliary	389,250	389,250
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	111.1	82.7
cfm/ft²	0.14	0.14
cfm/ton	155.50	
ft²/ton	1,116.87	
Btu/hr-ft²	10.74	-12.33
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	127.4	1,528.4	1,125.6	49,577	75.1	61.0	61.2	54.0	49.8	48.9
Aux Clg	677.6	8,131.1	6,920.9	389,250	72.0	59.9	61.2	55.2	52.4	56.9
Opt Vent	191.5	2,297.4	1,265.9	55,071	74.6	66.2	87.5	53.1	52.3	60.0
Total	996.4	11,956.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	93,535	45,032	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-3,167.6	49,577	64.7	124.6
Aux Htg	-2,219.2	389,250	68.0	73.3
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-1,223.6	55,071	49.2	70.0
Total	-6,610.3			

Hybrid GSHP w/ All DOAS FCU (Cooling 996.4 Tons, Heating 6,610.3 MBH)

System Checksums

By PENN STATE UNIVERSITY

Core — Active Chilled Beams

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 9 / 11; Outside Air: OADB/WB/HR: 70 / 59 / 62

CLG Space Peak — Mo/Hr: 11 / 12; OADB: 54

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	-10,635	-10,635	0	0	0
Glass Solar	1,692,315	0	1,692,315	47	2,066,419	65
Glass/Door Cond	-46,233	0	-46,233	-1	-210,801	-7
Wall Cond	39,015	50,860	89,876	2	35,506	1
Partition/Door	-13,359		-13,359	0	-32,630	-1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	-38,246		-38,246	-1	-208,388	-7
Sub Total ==>	1,633,491	40,225	1,673,717	46	1,650,106	52
Internal Loads						
Lights	93,995	375,981	469,977	13	95,225	3
People	1,965,224	0	1,965,224	54	911,679	29
Misc	468,932	0	468,932	13	472,256	15
Sub Total ==>	2,528,152	375,981	2,904,133	80	1,479,160	47
Ceiling Load	147,685	-147,685	0	0	135,183	4
Ventilation Load	-821,140	0	-821,140	-23	-100,296	-3
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	-403		-403	0	-403	0
Exhaust Heat		-133,707	-133,707	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	3,487,785	134,816	3,622,602	100.00	3,163,751	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-87,567	2.82
Glass Solar	0	0	0.00
Glass/Door Cond	-739,251	-739,251	23.78
Wall Cond	-101,576	-225,284	7.25
Partition/Door	-71,618	-71,618	2.30
Floor	-5,141	-5,141	0.17
Adjacent Floor	0	0	0
Infiltration	-745,944	-745,944	24.00
Sub Total ==>	-1,663,530	-1,874,804	60.31
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-5.74
Sub Total ==>	178,595	178,595	-5.74
Ceiling Load	-83,448	0	0.00
Ventilation Load	-497,926	-497,925	16.02
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		52,340	-1.68
OA Preheat Diff.		-966,923	31.10
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-2,066,308	-3,108,716	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	68.0
Ra Plenum	74.2	66.8
Return	74.2	66.8
Ret/OA	74.2	66.8
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	54,146	58,013
Terminal	54,146	58,013
Main Fan	54,146	58,013
Sec Fan	0	0
Nom Vent	46,983	29,155
AHU Vent	46,983	29,155
Infil	11,093	11,093
MinStop/Rh	0	0
Return	112,222	98,261
Exhaust	58,076	40,248
Rm Exh	0	0
Auxiliary	336,953	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	86.8	50.3
cfm/ft²	0.25	0.27
cfm/ton	211.97	
ft²/ton	845.92	
Btu/hr·ft²	14.19	-4.82
No. People	3,901	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	107.2	1,286.4	332.5	43,383	74.2	60.7	61.2	55.0	49.9	47.6
Aux Clg	194.7	2,336.2	2,336.2	336,953	72.0	59.9	61.2	65.5	57.5	61.2
Opt Vent	148.2	1,778.9	922.1	46,983	71.5	65.1	86.8	53.1	52.4	60.0
Total	450.1	5,401.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	216,088		
Part	9,136		
Int Door	0		
ExFlr	408		
Roof	46,777	0	0
Wall	28,531	13,703	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-75.4	58,013	66.8	68.0
Aux Htg	-1,726.7	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-966.9	46,983	50.7	70.0
Total	-2,769.0			

Core of Central Plant w/ ACB/DOAS FCU (Cooling 450.1 Tons, Heating 2,769.0 MBH)

System Checksums

By PENN STATE UNIVERSITY

Perimeter — **4-pipe Induction**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

Clg Space Peak — Mo/Hr: 7 / 15; OADB: 86

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	21,382	21,382	1	0	0
Glass Solar	1,948,689	0	1,948,689	59	1,336,656	64
Glass/Door Cond	277,748	0	277,748	8	333,465	16
Wall Cond	196,300	341,095	537,396	16	167,825	8
Partition/Door	14,716		14,716	0	16,744	1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	208,661		208,661	6	83,195	4
Sub Total ==>	2,646,115	362,478	3,008,592	92	1,939,908	92
Internal Loads						
Lights	54,809	219,236	274,045	8	52,156	2
People	278,117	0	278,117	8	161,246	8
Misc	117,088	0	117,088	4	117,374	6
Sub Total ==>	450,014	219,236	669,250	20	330,776	16
Ceiling Load	149,575	-149,575	0	0	149,527	7
Ventilation Load	-382,082	0	-382,082	-12	-422,242	-20
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	107,815		107,815	3	107,815	5
Exhaust Heat		-126,767	-126,767	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		-36,816	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	2,971,437	268,556	3,276,809	100.00	2,105,784	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-40,998	1.01
Glass Solar	0	0	0.00
Glass/Door Cond	-1,644,224	-1,644,224	40.33
Wall Cond	-279,716	-776,054	19.03
Partition/Door	-137,968	-137,968	3.38
Floor	-13,860	-13,860	0.34
Adjacent Floor	0	0	0
Infiltration	-452,632	-452,632	11.10
Sub Total ==>	-2,528,400	-3,065,736	75.19
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-198,982	0	0.00
Ventilation Load	-502,797	-502,797	12.33
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	1	1	0.00
Exhaust Heat		173,202	-4.25
OA Preheat Diff.		-681,907	16.72
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-3,230,178	-4,077,237	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	124.4
Ra Plenum	75.4	63.5
Return	75.6	63.5
Ret/OA	75.6	63.5
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	34,492	34,492
Terminal	34,492	34,492
Main Fan	34,492	34,492
Sec Fan	0	0
Nom Vent	25,687	29,441
AHU Vent	25,687	29,441
Infil	6,731	6,731
MinStop/Rh	0	0
Return	66,911	70,664
Exhaust	32,419	36,172
Rm Exh	0	0
Auxiliary	180,289	180,289
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	74.5	85.4
cfm/ft²	0.25	0.25
cfm/ton	188.00	
ft²/ton	763.02	
Btu/hr·ft²	15.73	-20.88
No. People	695	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	81.1	973.4	836.2	34,492	75.6	61.2	61.2	54.0	51.1	53.6
Aux Clg	304.5	3,653.3	3,323.6	180,289	72.0	59.9	61.2	55.1	52.6	57.9
Opt Vent	102.4	1,228.2	676.8	29,441	74.6	66.2	87.5	53.1	52.3	60.0
Total	487.9	5,854.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	139,988		
Part	17,600		
Int Door	0		
ExFlr	1,100		
Roof	23,124	0	0
Wall	65,004	31,330	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-2,240.9	34,492	63.5	124.4
Aux Htg	-1,111.9	180,289	68.0	73.8
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-681.9	29,441	48.3	70.0
Total	-4,034.7			

Perimeter of Central Plant w/ ACB/DOAS FCU (Cooling 487.9 Tons, Heating 4034.7 MB)

System Checksums

By PENN STATE UNIVERSITY

Perimeter — **4-pipe Induction**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

Clg Space Peak — Mo/Hr: 7 / 15; OADB: 86

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	21,362	21,362	1	0	0
Glass Solar	1,948,689	0	1,948,689	59	1,338,658	64
Glass/Door Cond	277,748	0	277,748	8	333,485	16
Wall Cond	196,300	341,095	537,396	16	167,825	8
Partition/Door	14,716		14,716	0	16,744	1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	208,661		208,661	6	83,195	4
Sub Total ==>	2,646,115	362,478	3,008,592	92	1,939,908	92
Internal Loads						
Lights	54,809	219,236	274,045	8	52,156	2
People	278,117	0	278,117	8	161,246	8
Misc	117,088	0	117,088	4	117,374	6
Sub Total ==>	450,014	219,236	669,250	20	330,776	16
Ceiling Load	149,575	-149,575	0	0	149,527	7
Ventilation Load	-382,082	0	-382,082	-12	-422,242	-20
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	107,815		107,815	3	107,815	5
Exhaust Heat		-126,767	-126,767	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		-36,816	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	2,971,437	268,556	3,276,809	100.00	2,105,784	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-40,998	1.01
Glass Solar	0	0	0.00
Glass/Door Cond	-1,644,224	-1,644,224	40.33
Wall Cond	-279,716	-776,054	19.03
Partition/Door	-137,968	-137,968	3.38
Floor	-13,860	-13,860	0.34
Adjacent Floor	0	0	0
Infiltration	-452,632	-452,632	11.10
Sub Total ==>	-2,528,400	-3,065,736	75.19
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-198,982	0	0.00
Ventilation Load	-502,797	-502,797	12.33
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	1	1	0.00
Exhaust Heat		173,202	-4.25
OA Preheat Diff.		-681,907	16.72
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-3,230,178	-4,077,237	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	124.4
Ra Plenum	75.4	63.5
Return	75.6	63.5
Ret/OA	75.6	63.5
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	34,492	34,492
Terminal	34,492	34,492
Main Fan	34,492	34,492
Sec Fan	0	0
Nom Vent	25,687	29,441
AHU Vent	25,687	29,441
Infil	6,731	6,731
MinStop/Rh	0	0
Return	66,911	70,664
Exhaust	32,419	36,172
Rm Exh	0	0
Auxiliary	180,289	180,289
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	74.5	85.4
cfm/ft²	0.25	0.25
cfm/ton	188.00	
ft²/ton	763.02	
Btu/hr-ft²	15.73	-20.88
No. People	695	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	81.1	973.4	836.2	34,492	75.6	61.2	61.2	54.0	51.1	53.6
Aux Clg	304.5	3,653.3	3,323.6	180,289	72.0	59.9	61.2	55.1	52.6	57.9
Opt Vent	102.4	1,228.2	676.8	29,441	74.6	66.2	87.5	53.1	52.3	60.0
Total	487.9	5,854.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	139,988		
Part	17,600		
Int Door	0		
ExFlr	1,100		
Roof	23,124	0	0
Wall	65,004	31,330	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-2,240.9	34,492	63.5	124.4
Aux Htg	-1,111.9	180,289	68.0	73.8
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-681.9	29,441	48.3	70.0
Total	-4,034.7			

Perimeter of Hybrid GSHP w/ ACB/DOAS FCU (Cooling 487.9 Tons, Heating 4034.7 MB)

System Checksums

By PENN STATE UNIVERSITY

Core — Active Chilled Beams

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 9 / 11; Outside Air: OADB/WB/HR: 70 / 59 / 62

CLG Space Peak — Mo/Hr: 11 / 12; OADB: 54

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	-10,635	-10,635	0	0	0
Glass Solar	1,692,315	0	1,692,315	47	2,066,419	65
Glass/Door Cond	-46,233	0	-46,233	-1	-210,801	-7
Wall Cond	39,015	50,860	89,876	2	35,506	1
Partition/Door	-13,359		-13,359	0	-32,630	-1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	-38,246		-38,246	-1	-208,388	-7
Sub Total ==>	1,633,491	40,225	1,673,717	46	1,650,106	52
Internal Loads						
Lights	93,995	375,981	469,977	13	95,225	3
People	1,965,224	0	1,965,224	54	911,679	29
Misc	468,932	0	468,932	13	472,256	15
Sub Total ==>	2,528,152	375,961	2,904,133	80	1,479,160	47
Ceiling Load	147,685	-147,685	0	0	135,183	4
Ventilation Load	-821,140	0	-821,140	-23	-100,296	-3
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	-403		-403	0	-403	0
Exhaust Heat		-133,707	-133,707	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	3,487,765	134,616	3,622,602	100.00	3,163,751	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-87,567	2.82
Glass Solar	0	0	0.00
Glass/Door Cond	-739,251	-739,251	23.78
Wall Cond	-101,576	-225,284	7.25
Partition/Door	-71,618	-71,618	2.30
Floor	-5,141	-5,141	0.17
Adjacent Floor	0	0	0
Infiltration	-745,944	-745,944	24.00
Sub Total ==>	-1,663,530	-1,874,804	60.31
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-5.74
Sub Total ==>	178,595	178,595	-5.74
Ceiling Load	-83,448	0	0.00
Ventilation Load	-497,926	-497,925	16.02
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		52,340	-1.68
OA Preheat Diff.		-966,923	31.10
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-2,066,308	-3,108,716	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	68.0
Ra Plenum	74.2	66.8
Return	74.2	66.8
Ret/OA	74.2	66.8
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	54,146	58,013
Terminal	54,146	58,013
Main Fan	54,146	58,013
Sec Fan	0	0
Nom Vent	46,983	29,155
AHU Vent	46,983	29,155
Infil	11,093	11,093
MinStop/Rh	0	0
Return	112,222	98,261
Exhaust	58,076	40,248
Rm Exh	0	0
Auxiliary	336,953	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	86.8	50.3
cfm/ft²	0.25	0.27
cfm/ton	211.97	
ft²/ton	845.92	
Btu/hr-ft²	14.19	-4.82
No. People	3,901	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	107.2	1,286.4	332.5	43,383	74.2	60.7	61.2	55.0	49.9	47.6
Aux Clg	194.7	2,336.2	2,336.2	336,953	72.0	59.9	61.2	65.5	57.5	61.2
Opt Vent	148.2	1,778.9	922.1	46,983	71.5	65.1	86.8	53.1	52.4	60.0
Total	450.1	5,401.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	216,088		
Part	9,136		
Int Door	0		
ExFlr	408		
Roof	46,777	0	0
Wall	28,531	13,703	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-75.4	58,013	66.8	68.0
Aux Htg	-1,726.7	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Reheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-966.9	46,983	50.7	70.0
Total	-2,769.0			

Core of Hybrid GSHP w/ ACB/DOAS FCU (Cooling 450.1 Tons, Heating 2,769.0 MBH)

System Checksums

By PENN STATE UNIVERSITY

Perimeter — **4-pipe Induction**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

Clg Space Peak — Mo/Hr: 7 / 15; OADB: 86

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	12,654	12,654	1	0	0
Glass Solar	613,061	0	613,061	40	575,849	50
Glass/Door Cond	183,168	0	183,168	12	235,150	21
Wall Cond	154,818	250,270	405,088	26	127,802	11
Partition/Door	13,490		13,490	1	16,744	1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	150,031		150,031	10	61,726	5
Sub Total ==>	1,114,567	262,924	1,377,492	90	1,017,272	89
Internal Loads						
Lights	40,752	163,007	203,759	13	37,900	3
People	156,664	0	156,664	10	96,578	8
Misc	57,440	0	57,440	4	60,066	5
Sub Total ==>	254,856	163,007	417,863	27	194,544	17
Ceiling Load	129,299	-129,299	0	0	127,498	11
Ventilation Load	-236,242	0	-236,242	-15	-271,428	-24
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	78,923		78,923	5	78,923	7
Exhaust Heat		-100,235	-100,235	-7		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,341,404	196,398	1,537,801	100.00	1,146,809	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-25,917	0.89
Glass Solar	0	0	0.00
Glass/Door Cond	-1,158,658	-1,158,658	39.82
Wall Cond	-200,890	-522,060	17.94
Partition/Door	-137,968	-137,968	4.74
Floor	-13,860	-13,860	0.48
Adjacent Floor	0	0	0
Infiltration	-353,909	-353,909	12.16
Sub Total ==>	-1,865,284	-2,212,371	76.03
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-132,392	0	0.00
Ventilation Load	-345,385	-345,385	11.87
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	1	1	0.00
Exhaust Heat		107,798	-3.70
OA Preheat Diff.		-460,059	15.81
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-2,343,060	-2,910,016	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	124.0
Ra Plenum	75.9	64.0
Return	76.3	64.0
Ret/OA	76.3	64.0
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	25,275	25,275
Terminal	25,275	25,275
Main Fan	25,275	25,275
Sec Fan	0	0
Nom Vent	16,470	20,224
AHU Vent	16,470	20,224
Infil	5,263	5,263
MinStop/Rh	0	0
Return	47,008	50,762
Exhaust	21,733	25,487
Rm Exh	0	0
Auxiliary	83,744	83,744
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	65.2	80.0
cfm/ft²	0.24	0.24
cfm/ton	199.45	
ft²/ton	832.07	
Btu/hr-ft²	14.42	-19.71
No. People	426	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	56.4	677.0	577.2	25,275	76.3	61.4	61.2	55.0	51.9	55.1
Aux Clg	158.8	1,905.6	1,552.7	83,744	72.0	59.9	61.2	55.0	51.7	54.4
Opt Vent	70.3	843.7	454.9	20,224	74.6	66.2	87.5	53.1	52.3	60.0
Total	285.5	3,426.3								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	105,444		
Part	17,600		
Int Door	0		
ExFlr	1,100		
Roof	14,488	0	0
Wall	47,308	23,445	50
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-1,618.3	25,275	64.0	124.0
Aux Htg	-786.5	83,744	68.0	76.8
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-460.1	20,224	48.7	70.0
Total	-2,864.8			

Perimeter of Hybrid GSHP w/ ACB/DOAS FCU w/ Façade Redesign

(Cooling 285.5 Tons, Heating 2864.8 MBH)

System Checksums

By PENN STATE UNIVERSITY

Core | Active Chilled Beams

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 9 / 15; Outside Air: OADB/WB/HR: 79 / 63 / 67

CLG Space Peak — Mo/Hr: 11 / 12; OADB: 54

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	10,039	10,039	0	0	0
Glass Solar	1,344,573	0	1,344,573	36	1,775,850	62
Glass/Door Cond	85,393	0	85,393	2	-267,716	-9
Wall Cond	107,459	130,139	237,598	6	19,637	1
Partition/Door	-10,643		-10,643	0	-32,630	-1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	121,979		121,979	3	-238,727	-8
Sub Total ==>	1,648,760	140,179	1,788,939	48	1,256,414	44
Internal Loads						
Lights	103,451	413,804	517,254	14	112,019	4
People	1,936,618	0	1,936,618	52	969,864	34
Misc	504,811	0	504,811	14	533,699	19
Sub Total ==>	2,544,879	413,804	2,958,683	80	1,615,581	56
Ceiling Load	170,078	-170,078	0	0	115,325	4
Ventilation Load	-882,068	0	-882,068	-24	-108,341	-4
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	-1,169		-1,169	0	-1,169	0
Exhaust Heat		-143,092	-143,092	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		-43,347	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	3,480,480	197,465	3,721,293	100.00	2,877,810	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-104,390	2.76
Glass Solar	0	0	0.00
Glass/Door Cond	-946,169	-946,169	25.01
Wall Cond	-196,415	-436,872	11.55
Partition/Door	-71,618	-71,618	1.89
Floor	-5,141	-5,141	0.14
Adjacent Floor	0	0	0
Infiltration	-854,544	-854,544	22.59
Sub Total ==>	-2,073,886	-2,418,733	63.94
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-4.72
Sub Total ==>	178,595	178,595	-4.72
Ceiling Load	-143,445	0	0.00
Ventilation Load	-562,285	-562,285	14.86
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		86,763	-2.29
OA Preheat Diff.		-1,067,053	28.21
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-2,601,021	-3,782,712	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	68.0
Ra Plenum	74.1	66.2
Return	74.1	66.2
Ret/OA	74.1	66.2
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	49,222	60,275
Terminal	49,222	60,275
Main Fan	49,222	60,275
Sec Fan	0	0
Nom Vent	50,752	32,924
AHU Vent	50,752	32,924
Infil	12,708	12,708
MinStop/Rh	0	0
Return	112,681	105,906
Exhaust	63,459	45,632
Rm Exh	0	0
Auxiliary	350,198	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	103.1	54.6
cfm/ft²	0.19	0.24
cfm/ton	183.68	
ft²/ton	948.19	
Btu/hr-ft²	12.66	-4.65
No. People	4,167	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter °F	Enter gr/lb	Leave DB/WB/HR °F	Leave °F	Leave gr/lb
Main Clg	107.8	1,294.0	279.5	40,611	74.1	60.7	61.2	54.0	49.0	45.8
Aux Clg	202.3	2,427.3	2,427.3	350,198	72.0	59.9	61.2	65.5	57.5	61.2
Opt Vent	160.1	1,921.6	996.0	50,752	71.5	65.1	86.8	53.1	52.4	60.0
Total	470.2	5,642.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	254,088		
Part	9,136		
Int Door	0		
ExFlr	408		
Roof	56,277	0	0
Wall	39,731	17,063	43
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-114.6	60,275	66.2	68.0
Aux Htg	-2,194.3	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-1,067.1	50,752	50.3	70.0
Total	-3,375.9			

Core of Hybrid GSHP w/ ACB/DOAS FCU w/ Façade Redesign

(Cooling 470.2 Tons, Heating 3375.9 MBH)

System Checksums

By PENN STATE UNIVERSITY

Main System — **Active Chilled Beams**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

Clg Space Peak — Mo/Hr: 11 / 12; OADB: 54

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	48,876	48,876	4,478	0	0
Glass Solar	1,336,398	0	1,336,398	122,430	2,583,064	71
Glass/Door Cond	389,811	0	389,811	35,711	-541,452	-15
Wall Cond	203,636	307,008	510,644	46,781	113,128	3
Partition/Door	-1,959		-1,959	-179	-95,238	-3
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	668,039		668,039	61,200	-334,838	-9
Sub Total ==>	2,595,925	355,884	2,951,809	270,421	1,724,664	48
Internal Loads						
Lights	145,123	580,493	725,617	66,475	156,863	4
People	2,111,904	0	2,111,904	193,476	1,063,340	29
Misc	564,731	0	564,731	51,736	599,069	17
Sub Total ==>	2,821,758	580,493	3,402,251	311,687	1,819,272	50
Ceiling Load	293,802	-293,802	0	0	222,454	6
Ventilation Load	-1,012,213	0	-1,012,213	-92,731	-136,843	-4
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			740,373	67,827		
Ov/Undr Sizing	-5,850,812		-5,850,812	-536,005	0	0
Exhaust Heat		-230,318	-230,318	-21,100		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	-1,151,539	412,257	1,092	100.00	3,627,547	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-128,779	1.69
Glass Solar	0	0	0.00
Glass/Door Cond	-1,928,256	-1,928,256	25.25
Wall Cond	-322,625	-796,214	10.43
Partition/Door	-209,586	-209,586	2.74
Floor	-19,001	-19,001	0.25
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	15.70
Sub Total ==>	-3,678,043	-4,280,411	56.05
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-2.34
Sub Total ==>	178,595	178,595	-2.34
Ceiling Load	-248,039	0	0.00
Ventilation Load	-870,412	-870,411	11.40
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		161,400	-2.11
OA Preheat Diff.		-1,388,876	18.19
RA Preheat Diff.		0	0.00
Additional Reheat		-1,436,855	18.82
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-4,617,898	-7,636,557	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	72.0
Ra Plenum	74.6	65.8
Return	74.6	65.8
Ret/OA	74.6	65.8
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	17,481	82,210
Terminal	17,481	82,210
Main Fan	17,481	82,210
Sec Fan	0	0
Nom Vent	65,040	50,966
AHU Vent	65,040	50,966
Infil	17,824	17,824
MinStop/Rh	82,210	82,210
Return	100,345	151,000
Exhaust	82,864	68,790
Rm Exh	0	0
Auxiliary	478,044	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	372.1	62.0
cfm/ft²	0.05	0.23
cfm/ton	85.18	
ft²/ton	1,735.11	
Btu/hr-ft²	6.92	-9.46
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Aux Clg	275.9	3,310.6	3,310.6	478,044	72.0	59.9	61.2	65.5	57.5	61.2
Opt Vent	205.2	2,462.6	1,276.4	65,040	71.5	65.1	86.8	53.1	52.4	60.0
Total	481.1	5,773.2								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	77,855	37,640	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-1,981.2	82,210	49.4	72.0
Aux Htg	-3,871.8	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Reheat	-1,981.2	82,210	49.4	72.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-1,388.9	65,040	50.0	70.0
Total	-7,241.8			

Central Plant w/ All Active Chilled Beam w/ Façade Redesign

(Cooling 481.1 Tons, Heating 7241.8 MBH)

System Checksums

By PENN STATE UNIVERSITY

Main System — **Active Chilled Beams**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling coil peak: Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

CLG space peak: Mo/Hr: 11 / 12; OADB: 54

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	48,876	48,876	4,478	0	0
Glass Solar	1,336,398	0	1,336,398	122,430	2,583,064	71
Glass/Door Cond	389,811	0	389,811	35,711	-541,452	-15
Wall Cond	203,636	307,008	510,644	46,781	113,128	3
Partition/Door	-1,959		-1,959	-179	-95,238	-3
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	668,039		668,039	61,200	-334,838	-9
Sub Total ==>	2,595,925	355,884	2,951,809	270,421	1,724,664	48
Internal Loads						
Lights	145,123	580,493	725,617	66,475	156,863	4
People	2,111,904	0	2,111,904	193,476	1,063,340	29
Misc	564,731	0	564,731	51,736	599,069	17
Sub Total ==>	2,821,758	580,493	3,402,251	311,687	1,819,272	50
Ceiling Load	293,802	-293,802	0	0	222,454	6
Ventilation Load	-1,012,213	0	-1,012,213	-92,731	-138,843	-4
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			740,373	67,827		
Ov/Undr Sizing	-5,850,812		-5,850,812	-536,005	0	0
Exhaust Heat		-230,318	-230,318	-21,100		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	-1,151,539	412,257	1,092	100.00	3,627,547	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-128,779	1.69
Glass Solar	0	0	0.00
Glass/Door Cond	-1,928,256	-1,928,256	25.25
Wall Cond	-322,625	-796,214	10.43
Partition/Door	-209,586	-209,586	2.74
Floor	-19,001	-19,001	0.25
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	15.70
Sub Total ==>	-3,678,043	-4,280,411	56.05
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-2.34
Sub Total ==>	178,595	178,595	-2.34
Ceiling Load	-248,039	0	0.00
Ventilation Load	-670,412	-670,411	11.40
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		161,400	-2.11
OA Preheat Diff.		-1,388,876	18.19
RA Preheat Diff.		0	0.00
Additional Reheat		-1,436,855	18.82
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-4,617,898	-7,636,557	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	72.0
Ra Plenum	74.6	65.8
Return	74.6	65.8
Ret/OA	74.6	65.8
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	17,481	82,210
Terminal	17,481	82,210
Main Fan	17,481	82,210
Sec Fan	0	0
Nom Vent	65,040	50,966
AHU Vent	65,040	50,966
Infil	17,824	17,824
MinStop/Rh	82,210	82,210
Return	100,345	151,000
Exhaust	82,864	68,790
Rm Exh	0	0
Auxiliary	478,044	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	372.1	62.0
cfm/ft²	0.05	0.23
cfm/ton	85.18	
ft²/ton	1,735.11	
Btu/hr·ft²	6.92	-9.46
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Aux Clg	275.9	3,310.6	3,310.6	478,044	72.0	59.9	61.2	65.5	57.5	61.2
Opt Vent	205.2	2,462.6	1,276.4	65,040	71.5	65.1	86.8	53.1	52.4	60.0
Total	481.1	5,773.2								

AREAS

	Gross Total	Glass ft²	(%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	77,855	37,640	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-1,981.2	82,210	49.4	72.0
Aux Htg	-3,871.8	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Reheat	-1,981.2	82,210	49.4	72.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-1,388.9	65,040	50.0	70.0
Total	-7,241.8			

Hybrid GSHP w/ All Active Chilled Beam w/ Façade Redesign

(Cooling 481.1 Tons, Heating 7241.8 MBH)

System Checksums

By PENN STATE UNIVERSITY

Main System — 4-pipe Induction

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

Clg Space Peak — Mo/Hr: 7 / 15; OADB: 86

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	70,508	70,508	1	0	0
Glass Solar	1,419,268	0	1,419,268	27	1,366,137	39
Glass/Door Cond	331,570	0	331,570	6	388,249	11
Wall Cond	246,552	356,137	602,689	12	217,814	6
Partition/Door	20,284		20,284	0	25,612	1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	593,555		593,555	11	225,717	6
Sub Total ==>	2,611,250	426,645	3,037,894	58	2,223,528	64
Internal Loads						
Lights	140,578	562,313	702,891	13	134,274	4
People	1,753,763	0	1,753,763	33	912,856	26
Misc	562,367	0	562,367	11	554,533	16
Sub Total ==>	2,456,708	562,313	3,019,021	58	1,601,663	46
Ceiling Load	359,617	-359,617	0	0	361,014	10
Ventilation Load	-735,617	0	-735,617	-14	-817,756	-23
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	124,836		124,836	2	124,836	4
Exhaust Heat		-209,221	-209,221	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		-44,501	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	4,816,794	375,619	5,236,914	100.00	3,493,284	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-127,470	2.30
Glass Solar	0	0	0.00
Glass/Door Cond	-1,928,256	-1,928,256	34.81
Wall Cond	-322,625	-791,399	14.29
Partition/Door	-209,586	-209,586	3.78
Floor	-19,001	-19,001	0.34
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	21.64
Sub Total ==>	-3,678,043	-4,274,288	77.17
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,596	-3.22
Sub Total ==>	178,595	178,596	-3.22
Ceiling Load	-317,779	0	0.00
Ventilation Load	-565,474	-565,475	10.21
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	3	3	0.00
Exhaust Heat		153,106	-2.76
OA Preheat Diff.		-1,030,648	18.61
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-4,382,698	-5,538,705	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	123.7
Ra Plenum	75.2	65.2
Return	75.2	65.2
Ret/OA	75.4	65.2
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	41,692	41,692
Terminal	41,692	41,692
Main Fan	41,692	41,692
Sec Fan	0	0
Nom Vent	47,185	33,111
AHU Vent	47,185	33,111
Infil	17,824	17,824
MinStop/Rh	0	0
Return	106,701	92,627
Exhaust	65,009	50,935
Rm Exh	0	0
Auxiliary	293,886	293,886
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	113.2	79.4
cfm/ft²	0.12	0.12
cfm/ton	151.26	
ft²/ton	1,291.85	
Btu/hr-ft²	9.29	-10.21
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	111.6	1,339.2	941.5	41,692	75.2	61.0	61.2	54.0	49.3	47.1
Aux Clg	534.8	6,417.0	5,057.0	293,886	72.0	59.9	61.2	55.1	52.0	55.6
Opt Vent	164.0	1,968.4	1,084.7	47,185	74.6	66.2	87.5	53.1	52.3	60.0
Total	810.4	9,724.6								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	77,855	37,640	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-2,604.8	41,692	65.2	123.7
Aux Htg	-2,066.2	293,886	68.0	74.6
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-1,030.7	47,185	49.5	70.0
Total	-5,701.6			

Central Plant w/ All DOAS Fan Coil Units w/ Façade Redesign

(Cooling 810.4 Tons, Heating 5701.6 MBH)

System Checksums

By PENN STATE UNIVERSITY

Main System — **4-pipe Induction**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

Clg Space Peak — Mo/Hr: 7 / 15; OADB: 86

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	70,508	70,508	1	0	0
Glass Solar	1,419,288	0	1,419,288	27	1,366,137	39
Glass/Door Cond	331,570	0	331,570	6	388,249	11
Wall Cond	246,552	356,137	602,689	12	217,814	6
Partition/Door	20,284		20,284	0	25,612	1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	593,555		593,555	11	225,717	6
Sub Total ==>	2,611,250	426,645	3,037,894	58	2,223,528	64
Internal Loads						
Lights	140,578	562,313	702,891	13	134,274	4
People	1,753,763	0	1,753,763	33	912,856	26
Misc	562,367	0	562,367	11	554,533	16
Sub Total ==>	2,456,708	562,313	3,019,021	58	1,601,663	46
Ceiling Load	359,617	-359,617	0	0	361,014	10
Ventilation Load	-735,617	0	-735,617	-14	-817,756	-23
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	124,836		124,836	2	124,836	4
Exhaust Heat		-209,221	-209,221	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		-44,501	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	4,816,794	375,619	5,236,914	100.00	3,493,284	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-127,470	2.30
Glass Solar	0	0	0.00
Glass/Door Cond	-1,928,256	-1,928,256	34.81
Wall Cond	-322,625	-791,399	14.29
Partition/Door	-209,586	-209,586	3.78
Floor	-19,001	-19,001	0.34
Adjacent Floor	0	0	0
Infiltration	-1,198,576	-1,198,576	21.64
Sub Total ==>	-3,678,043	-4,274,288	77.17
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-3.22
Sub Total ==>	178,595	178,595	-3.22
Ceiling Load	-317,779	0	0.00
Ventilation Load	-565,474	-565,475	10.21
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	3	3	0.00
Exhaust Heat		153,106	-2.76
OA Preheat Diff.		-1,030,648	18.61
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-4,382,698	-5,538,705	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	123.7
Ra Plenum	75.2	65.2
Return	75.2	65.2
Ret/OA	75.4	65.2
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	41,692	41,692
Terminal	41,692	41,692
Main Fan	41,692	41,692
Sec Fan	0	0
Nom Vent	47,185	33,111
AHU Vent	47,185	33,111
Infil	17,824	17,824
MinStop/Rh	0	0
Return	106,701	92,627
Exhaust	65,009	50,935
Rm Exh	0	0
Auxiliary	293,886	293,886
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	113.2	79.4
cfm/ft²	0.12	0.12
cfm/ton	151.26	
ft²/ton	1,291.85	
Btu/hr·ft²	9.29	-10.21
No. People	4,597	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	111.6	1,339.2	941.5	41,692	75.2	61.0	61.2	54.0	49.3	47.1
Aux Clg	534.8	6,417.0	5,057.0	293,886	72.0	59.9	61.2	55.1	52.0	55.6
Opt Vent	164.0	1,968.4	1,084.7	47,185	74.6	66.2	87.5	53.1	52.3	60.0
Total	810.4	9,724.6								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	356,076		
Part	26,736		
Int Door	0		
ExFlr	1,508		
Roof	69,901	0	0
Wall	77,855	37,640	48
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-2,604.8	41,692	65.2	123.7
Aux Htg	-2,066.2	293,886	68.0	74.6
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-1,030.7	47,185	49.5	70.0
Total	-5,701.6			

Hybrid GSHP w/ All DOAS Fan Coil Units w/ Façade Redesign

(Cooling 810.4 Tons, Heating 5701.6 MBH)

System Checksums

By PENN STATE UNIVERSITY

Core — Active Chilled Beams

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 9 / 15; Outside Air: OADB/WB/HR: 79 / 63 / 67

CLG Space Peak — Mo/Hr: 11 / 12; OADB: 54

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	10,039	10,039	0	0	0
Glass Solar	1,344,573	0	1,344,573	36	1,775,850	62
Glass/Door Cond	85,393	0	85,393	2	-267,716	-9
Wall Cond	107,459	130,139	237,598	6	19,637	1
Partition/Door	-10,643		-10,643	0	-32,630	-1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	121,979		121,979	3	-238,727	-8
Sub Total ==>	1,646,760	140,179	1,786,939	48	1,256,414	44
Internal Loads						
Lights	103,451	413,804	517,254	14	112,019	4
People	1,936,618	0	1,936,618	52	969,864	34
Misc	504,811	0	504,811	14	533,699	19
Sub Total ==>	2,544,879	413,804	2,958,683	80	1,615,581	56
Ceiling Load	170,078	-170,078	0	0	115,325	4
Ventilation Load	-882,068	0	-882,068	-24	-108,341	-4
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	-1,169		-1,169	0	-1,169	0
Exhaust Heat		-143,092	-143,092	-4		
Sup. Fan Heat			0	0		
Ret. Fan Heat		1	1	0		
Duct Heat Pkup		-43,347	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	3,480,480	197,465	3,721,293	100.00	2,877,810	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-104,390	2.76
Glass Solar	0	0	0.00
Glass/Door Cond	-946,169	-946,169	25.01
Wall Cond	-196,415	-436,872	11.55
Partition/Door	-71,618	-71,618	1.89
Floor	-5,141	-5,141	0.14
Adjacent Floor	0	0	0
Infiltration	-854,544	-854,544	22.59
Sub Total ==>	-2,073,886	-2,418,733	63.94
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	178,595	178,595	-4.72
Sub Total ==>	178,595	178,595	-4.72
Ceiling Load	-143,445	0	0.00
Ventilation Load	-562,285	-562,285	14.86
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		86,763	-2.29
OA Preheat Diff.		-1,067,053	28.21
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-2,601,021	-3,782,712	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	68.0
Ra Plenum	74.1	66.2
Return	74.1	66.2
Ret/OA	74.1	66.2
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	49,222	60,275
Terminal	49,222	60,275
Main Fan	49,222	60,275
Sec Fan	0	0
Nom Vent	50,752	32,924
AHU Vent	50,752	32,924
Infil	12,708	12,708
MinStop/Rh	0	0
Return	112,681	105,906
Exhaust	63,459	45,632
Rm Exh	0	0
Auxiliary	350,198	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	103.1	54.6
cfm/ft²	0.19	0.24
cfm/ton	183.68	
ft²/ton	946.19	
Btu/hr-ft²	12.66	-4.65
No. People	4,167	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	107.8	1,294.0	279.5	40,611	74.1	60.7	61.2	54.0	49.0	45.8
Aux Clg	202.3	2,427.3	2,427.3	350,198	72.0	59.9	61.2	65.5	57.5	61.2
Opt Vent	160.1	1,921.6	996.0	50,752	71.5	65.1	86.8	53.1	52.4	60.0
Total	470.2	5,642.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	254,068		
Part	9,136		
Int Door	0		
ExFlr	408		
Roof	56,277	0	0
Wall	39,731	17,063	43
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-114.6	60,275	66.2	68.0
Aux Htg	-2,194.3	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-1,067.1	50,752	50.3	70.0
Total	-3,375.9			

Core of Central Plant w/ ACB/DOAS FCU w/ Façade Redesign

(Cooling 470.2 Tons, Heating 3375.9 MBH)

System Checksums

By PENN STATE UNIVERSITY

Perimeter — 4-pipe Induction

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

Clg Space Peak — Mo/Hr: 7 / 15; OADB: 86

	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	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	12,654	12,654	1	0	0
Glass Solar	613,061	0	613,061	40	575,849	50
Glass/Door Cond	183,168	0	183,168	12	235,150	21
Wall Cond	154,818	250,270	405,088	26	127,802	11
Partition/Door	13,490		13,490	1	16,744	1
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	150,031		150,031	10	61,726	5
Sub Total ==>	1,114,567	262,924	1,377,492	90	1,017,272	89
Internal Loads						
Lights	40,752	163,007	203,759	13	37,900	3
People	156,664	0	156,664	10	96,578	8
Misc	57,440	0	57,440	4	60,066	5
Sub Total ==>	254,856	163,007	417,863	27	194,544	17
Ceiling Load	129,299	-129,299	0	0	127,498	11
Ventilation Load	-236,242	0	-236,242	-15	-271,428	-24
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	78,923		78,923	5	78,923	7
Exhaust Heat		-100,235	-100,235	-7		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	1,341,404	196,398	1,537,801	100.00	1,146,809	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	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	-25,917	0.89
Glass Solar	0	0	0.00
Glass/Door Cond	-1,158,658	-1,158,658	39.82
Wall Cond	-200,890	-522,060	17.94
Partition/Door	-137,968	-137,968	4.74
Floor	-13,860	-13,860	0.48
Adjacent Floor	0	0	0
Infiltration	-353,909	-353,909	12.16
Sub Total ==>	-1,865,284	-2,212,371	76.03
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	-132,392	0	0.00
Ventilation Load	-345,385	-345,385	11.87
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	1	1	0.00
Exhaust Heat		107,798	-3.70
OA Preheat Diff.		-460,059	15.81
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	-2,343,060	-2,910,016	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	124.0
Ra Plenum	75.9	64.0
Return	76.3	64.0
Ret/OA	76.3	64.0
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	25,275	25,275
Terminal	25,275	25,275
Main Fan	25,275	25,275
Sec Fan	0	0
Nom Vent	16,470	20,224
AHU Vent	16,470	20,224
Infil	5,263	5,263
MinStop/Rh	0	0
Return	47,008	50,762
Exhaust	21,733	25,487
Rm Exh	0	0
Auxiliary	83,744	83,744
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	65.2	80.0
cfm/ft²	0.24	0.24
cfm/ton	199.45	
ft²/ton	832.07	
Btu/hr·ft²	14.42	-19.71
No. People	426	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	56.4	677.0	577.2	25,275	76.3	61.4	61.2	55.0	51.9	55.1
Aux Clg	158.8	1,905.6	1,552.7	83,744	72.0	59.9	61.2	55.0	51.7	54.4
Opt Vent	70.3	843.7	464.9	20,224	74.6	66.2	87.5	53.1	52.3	60.0
Total	285.5	3,426.3								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	105,444		
Part	17,600		
Int Door	0		
ExFlr	1,100		
Roof	14,488	0	0
Wall	47,308	23,445	50
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-1,618.3	25,275	64.0	124.0
Aux Htg	-786.5	83,744	68.0	76.8
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	-460.1	20,224	48.7	70.0
Total	-2,864.8			

Perimeter of Central Plant w/ ACB/DOAS FCU w/ Façade Redesign

(Cooling 285.5 Tons, Heating 2864.8 MBH)