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SALK HALL LABORATORY

AT THE UNIVERSITY OF
PITTSBURGH

[ALTERNATE SYSTEM ANALYSIS]

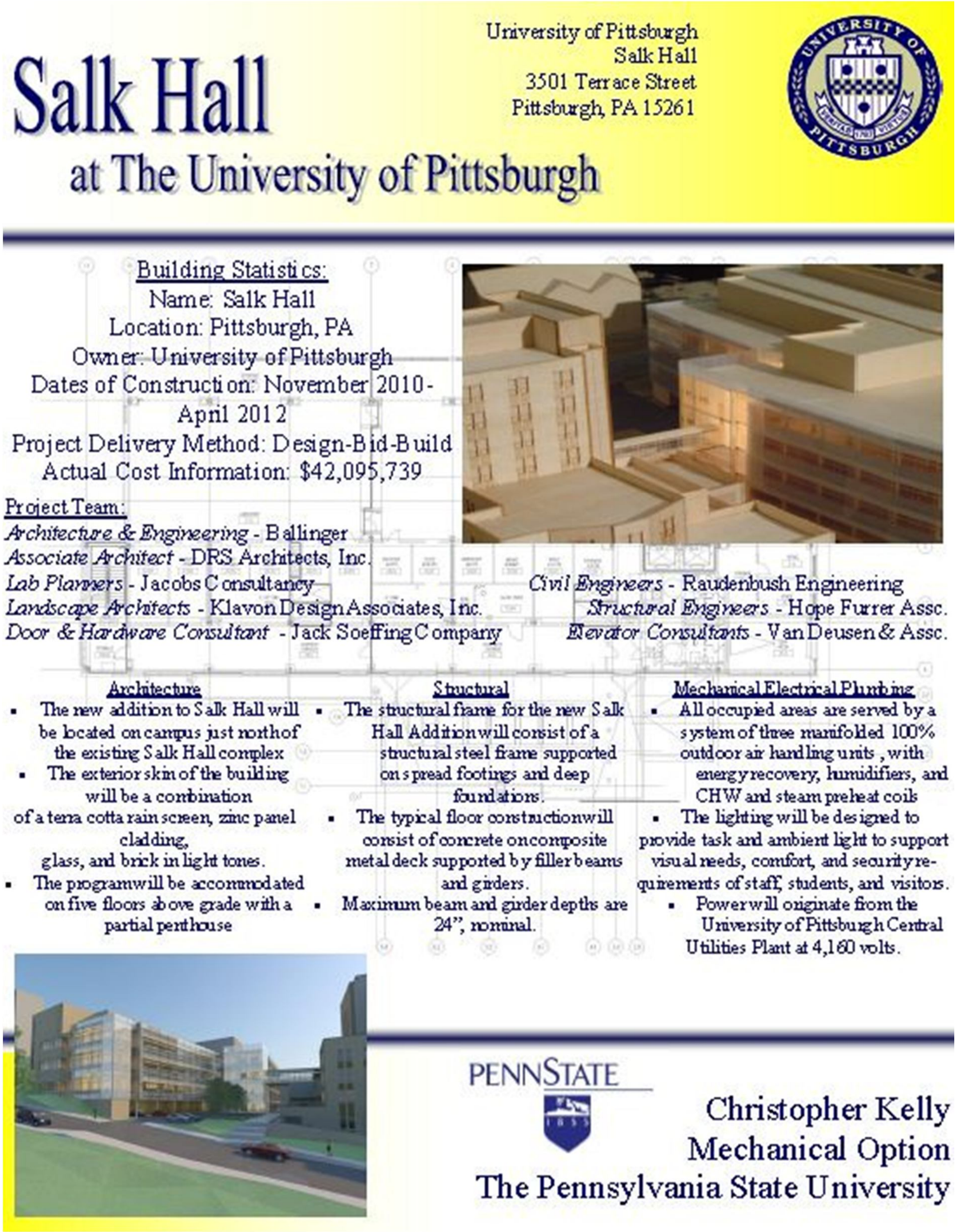
This senior thesis has been prepared by Christopher Kelly for the Pennsylvania State University's Architectural Engineering Department.

Table of Contents

List of Figures

List of Tables

Abstract



University of Pittsburgh
Salk Hall
3501 Terrace Street
Pittsburgh, PA 15261

Salk Hall
at The University of Pittsburgh

Building Statistics:
Name: Salk Hall
Location: Pittsburgh, PA
Owner: University of Pittsburgh
Dates of Construction: November 2010 - April 2012
Project Delivery Method: Design-Bid-Build
Actual Cost Information: $42,095,739

Project Team:
Architecture & Engineering - Ballinger
Associate Architect - DRS Architects, Inc.
Lab Planners - Jacobs Consultancy
Landscape Architects - Klavon Design Associates, Inc.
Door & Hardware Consultant - Jack Soeffing Company
Civil Engineers - Raudenbush Engineering
Structural Engineers - Hope Furrer Assc.
Elevator Consultants - Van Deusen & Assc.

Architecture

- The new addition to Salk Hall will be located on campus just north of the existing Salk Hall complex
- The exterior skin of the building will be a combination of a terra cotta rain screen, zinc panel cladding, glass, and brick in light tones.
- The program will be accommodated on five floors above grade with a partial penthouse

Structural

- The structural frame for the new Salk Hall Addition will consist of a structural steel frame supported on spread footings and deep foundations.
- The typical floor construction will consist of concrete on composite metal deck supported by filler beams and girders.
- Maximum beam and girder depths are 24", nominal.

Mechanical Electrical Plumbing

- All occupied areas are served by a system of three manifolded 100% outdoor air handling units, with energy recovery, humidifiers, and CHW and steam preheat coils
- The lighting will be designed to provide task and ambient light to support visual needs, comfort, and security requirements of staff, students, and visitors.
- Power will originate from the University of Pittsburgh Central Utilities Plant at 4,160 volts.

PENNSTATE

Christopher Kelly
Mechanical Option
The Pennsylvania State University

Executive Summary

The Salk Hall Addition is designed as an 81,116 square foot expansion of the existing Salk Hall laboratory. Salk Hall serves as an educational and research facility for the Department of Health Sciences, the School of Pharmacy, and the School of Dental Medicine at the University of Pittsburgh. Existing Salk hall was evaluated to determine necessary, or recommended, infrastructure upgrades and renovations in order to establish a program for the new building. The university re-started the design process in September 2009 after reducing the scope and budget from a larger project that was initially studied in 2008.

Overall, the designed mechanical system of the Salk Hall addition is appropriately sized and was found to adhere to local codes and industry standards. Laboratories often pose a greater design challenge than other buildings due to their large variation in internal loads and high ventilation requirements. The basis of design (BOD), with regard to the air-side system, incorporates a variable air volume design with enthalpy energy recovery. This system is capable of supplying the required ventilation airflow rate under full and part load conditions, as well as provided make-up ventilation air when fume hoods or biological safety cabinets are active. The hydronic system design incorporates a perimeter radiation heating system and a radiant floor heating system.

The estimated construction cost of the BOD’s mechanical system is around 11% of the total building cost. This percentage is within an appropriate range, with respect to the fact that laboratories require a large amount of specialized equipment and associated architectural casework. Since the Salk Hall Addition receives its utilities from campus plants, the most expensive pieces of mechanical equipment are the air handling units. Variable air volume systems are conventional, easy to install, and easy to operate.

The operating cost of the building is dominated by the ventilation requirement of the laboratories. In order to supply the laboratories with a ventilation rate of 8 air changes per hour (ACH), the electrical system has to meet the high full load amp demand of the supply fans. Specialized laboratory equipment also drives the building’s operation costs up with regards to the demand on the electrical system. The variety of lab equipment that is associated with Salk Hall can yield power consumption densities of 6-8 watts per square foot. In total, the associated operating costs of the BOD total to roughly $520,762. This yields a ratio of $6.42 per square foot.

The Salk Hall Addition demands a large quantity of hot water for its terminal reheat units, perimeter radiators, and other heating coil applications. The BOD does not directly recover any energy from the campus chiller.

One issue that the BOD may come across is a lack of capacity if the future program of the building changes. The BOD lacks 3,794 CFM to the meet the TRACE 700 peak simulated cooling load. While TRACE load simulations are often very conservative, this simulated demand does not include duct losses and could be problematic if extra fume hoods or biological safety cabinets are added to the building program.

Two identical, 33,000 CFM Pinnacle Ventilation Units will be designed to handle the combined thermal and ventilation loads required by the Salk Hall Addition's design program. One unit will exclusively handle thermal comfort by providing the chilled beams with neutral supply air. The other unit will provide 70°F supply air in order to meet the ventilation requirements of the Salk Hall Addition. The National Institute of Health requires that fume hood laboratories have back-up ventilation & exhaust systems. The AHUs are identical SEMCO PVS-43 air handling units, and in the case of a failure, the functioning air handler will service the ventilation system. Areas such as the linear equipment corridors, which have extremely high sensible loads, have been designed to incorporate auxiliary fan coil units in support of the main cooling system.

At its most fundamental level, rating the performance of an HVAC system is most simply exemplified in its annual operating cost. The BOD was estimated to have an annual operating cost of $520,762. The more efficient design, utilizing multiple heat recovery applications, was estimated to have an operating cost of $302,659. When comparing the two designs, the chilled beam yields a **$218,103 savings per year**. The future of HVAC systems lies with being able to minimize their carbon footprint. The traditional cool-and-reheat system is estimated to produce nearly 16 million pounds of pollutants annually. The active chilled beam system is estimated to produce around 10 million pounds of pollutants. The re-design would reduce Salk Hall’s carbon foot print by 37.5%.

Existing Systems & Conditions

Project Scope & Design Considerations

Project Scope

The scope of this project entails the construction of a new research tower, approximately 81,116 gross square feet, which will be connected to the existing Salk Hall Laboratory. The project will deliver the additional required research laboratories, and their associated ancillary spaces, for the Schools of Dental Medicine, Pharmacy, and the Graduate School of Public Health.

Figure 1-Existing Salk Hall Laboratory

The project includes renovations, upgrades, extensions, expansions and/or replacements of the following key systems:

1. HVAC
2. Electrical
3. Fire protection
4. Hydronic Systems

The design intent is to improve system function and energy efficiency while meeting applicable codes as well as accommodate the necessary upgrades and expansion of the buildings' research, teaching, administrative, and auxiliary facilities.

Building Program

The addition will physically connect to the existing building in selected locations, while reinforcing pedestrian access east and west across the site. The Salk Hall Addition is a five story research laboratory that is served by two mechanical rooms. The first floor serves as an administration/office space as well as containing the auxiliary mechanical room. Floors two through five are largely laboratory spaces. Private offices, as well as a conference room, are also located on floors two through five. The majority of the Salk Hall Addition's HVAC system is located in the mechanical penthouse above the fifth floor.

Site Information

Figure 2-Connection between existing and new buildings

The site for the Salk Hall Addition is located on the University of Pittsburgh's main campus and is situated within the 4th Ward of the City of Pittsburgh, Pennsylvania. The project area is currently under an existing asphalt parking lot and a heavily wooded hillside. Vehicular access is currently from Darragh Street. There is an existing loading dock and service area that is located south of the access point along Darragh Street. This area will be maintained and provide service for the Salk Hall addition. The construction of the Salk Hall Addition will eliminate an existing parking lot. However, the proposed layout provides eleven new parking spaces. The project area is not within any FEMA 100-year flood zones or preserved wetlands.

Basis of Design: Systems Analysis

Architectural Details

The exterior skin of the building is a combination of a terra cotta rain screen, zinc panel cladding, glass, and light-tone brick. The face brick will be modular, running bond, buff colored, and wire cut. The roofing system will consist of a white, single ply adhered membrane over a rigid polyisocyanurate insulation board, which mechanically attached to the structure. The curtain wall will be a semi-custom aluminum system with full thermal breaks including custom mullion covers.

Structural System

The structural frame for the Salk Hall Addition will consist of a structural steel frame, supported by a foundation of spread footings and deep foundations. Because the building is situated over an existing mine cavity, grout infill of the cavity will be required prior to placing the footings. The typical floor construction will consist of a concrete slab on composite metal deck, which will be supported by filler beams and girders. Maximum beam and girder depths are 24”. The mechanical level will be similar with regard to additional members, as required, to support the proposed equipment. All roof levels will consist of a metal roof deck supported by filler beams and girders. Columns will be W10 or W12 members. A pedestrian bridge will connect the 2nd Floor of the Addition with the 5th Floor of the existing Salk Hall. The bridge will be steel framed with girders spanning between buildings at the floor and roof levels.

Plumbing Systems

A new 4-inch potable water supply main will be provided for the Salk Hall Addition from an existing underground city potable water main. The new main will enter the building on the ground level. A main shut-off valve, water meter, and reduced pressure back-flow prevention assembly will be provided at the entrance location.

The domestic water supply system will be sized to include the building’s plumbing fixtures’ water loads, mechanical systems’ make-up water loads, emergency safety shower & eye wash water loads, laboratory water loads, and exterior wall hydrant loads. Domestic hot water and lab hot water will be generated at the ground floor level via two low-pressure steam-fired hot water generators; one for the lab hot water system and one for the domestic hot water system. Each duplex hot water generator for lab hot water system will be sized to satisfy 67% of the estimated system demand upon failure of any single hot water generator. Hot water will be distributed at 120°F. In-line centrifugal pumps will circulate the hot water system.

Sanitary waste from the basement floor to the penthouse will drain by gravity down through a 10-inch sanitary waste drainage header, located under the ground floor level. This sanitary waste building sewer will be routed to tie into the existing municipal sanitary waste sewer system.

Laboratory waste drainage piping system will be provided to convey laboratory waste and lab equipment drainage by gravity to the municipal sanitary waste sewer system in the street. Laboratory waste will drain by gravity down to a 6" inch laboratory waste main to the ground floor level. The waste will then connect to the sanitary waste system before exiting the building.

A storm drainage system will be provided to convey storm water by gravity from the roof to the municipal storm sewer system.

Electrical & Lighting Systems

Power will originate from the University of Pittsburgh Central Utilities Plant at 4,160 volts. The medium-voltage feeders will terminate in two substations in the Salk Hall Addition basement. One substation will serve all 480V loads in the building and the other will serve all 208V loads in the new building.

The building distribution will have one 480/277 volt substation with feeders to serve lighting and mechanical panels throughout the building and the motor control center in the mechanical penthouse. The building distribution will also have one 208/120 volt substation with feeders to serve all receptacle and laboratory loads in the building.

Emergency and standby power will be served from a single 600-kW standby diesel generator with a 24-hour supply of diesel fuel at 100% capacity.

The lighting will be designed to provide task and ambient light to support the visual needs, comfort, and security requirements of staff, students, and visitors. The design will include accent and effect lighting to reinforce the architectural design. Lighting equipment will be selected for energy efficiency and simplified lighting maintenance to minimize operating costs. The source for interior lighting will generally be fluorescent lamps operating on high-frequency solid-state electronic ballasts. Compact fluorescent lamps will be used in downlight and wall wash fixtures. Incandescent halogen lamps will be used for artwork, special accent, or dimming applications. Metal halide lighting will generally be used for exterior and parking lot lighting because of its superior color rendering capabilities compared to other HID sources.

Telecommunications

A Category-5e telecommunications distribution system will be designed for the building. The system will include cable tray, Category-5e outlets, cable, and rack-mounted patch panels. The building telecommunications cabling backbone will consist of 12-strand multimode fiber, 12-strand single mode fiber, and 300-pair copper cables distributed from the first floor MDF to an IDF on each floor.

The building will be connected to the campus network with 24-strand multimode and 24-strand single mode fiber optic cables to Scaife Hall. Additional fiber optic connections will include a replacement connection of 24-strand multimode and 24-strand single mode cable between Salk Hall and Fitzgerald Hall.

Fire Protection

Salk Hall is to be fully protected with a combination Automatic Class I Standpipe/Automatic wet-pipe fire sprinkler system in a Seismic Category A zone. The building fire protection systems will be monitored by the building fire alarm system at the Command Center. Hazardous material storage and use are limited to the maximum allowable per control area limits in accordance with the Pennsylvania Uniform Construction Code. Portable fire extinguishers will be provided in occupancies and locations as required by the International Fire Code by others.

ASHRAE Standards and LEED Analysis

This section will cover a selection of design considerations per industry standards.

ASHRAE Standard 55 Thermal Comfort (Relevant Design Considerations)

Section 5.2.1 Designing for Air Balancing

The laboratories and the majority of their support spaces are designed with variable air volume valves, in which the supply air can be adjusted based on the space requirements. The laboratory VAV system is also designed to introduce make-up air when the fume hoods or biological safety cabinets are operating. The offices and conference rooms are designed with commercial grade VAV boxes that also can vary the amount of airflow into each space. In regards to ventilation rates, the governing factor in office and administrative spaces is the occupancy density. Zones with constant volume valves are those in which ASHRAE Standard 62.1 does not specifically address, or zones whose ventilation is purely based on the square footage of the space. These spaces include restrooms, corridors, or unique laboratory support spaces such as cold rooms.

Section 5.3 Exhaust Duct Location

The design assumption is that each laboratory and the majority of its support spaces contain potentially harmful contaminants. These spaces are directly exhausted through the roof. Under experimental conditions, fume hoods and biological safety cabinets serve to protect the occupants by containing potentially harmful chemicals or biological specimen. These units are directly exhausted from the top of each unit and supply diffusers are directed away from their intakes to ensure that the contaminants are not dispersed with the room air.

Section 5.6.1 Outdoor Air Intake Location

Outdoor air will be entrained through wall louvers on the north side of the building into a double-wall, accessible plenum. The outdoor air intake and exhaust discharge vectors are perpendicular to each other. Bypass outdoor air will be introduced into the exhaust plenum through a modulating control damper to maintain constant stack discharge velocity for adequate dispersion of the exhaust air contaminants. The supply intake is sufficiently far enough away to comply with this section.

Section 5.7 Local Capture of Contaminants

Fume hoods and biological safety cabinets capture local contaminants in the laboratories and laboratory support spaces. These are directly exhausted through the roof after passing through a MERV 7 filter and the enthalpy energy recovery wheels located in each air handler. Fume hood exhaust airflow rates will be based on hoods with average face velocities of 100 feet per minute with a sash open height of 18”. Sash stops will be integrated with the fume hoods so that operators are alarmed when the 18” opening has been exceeded.

Section 5.9 Particulate Matter Removal

MERV 6 filters are required upstream of all cooling coils or other devices with wetted surfaces through which air is supplied to an occupied space. MERV 7 pre-filters are located on both the supply and exhaust side of the air distribution system. MERV 14 filters are downstream of the pre-filters on the supply side.

ASHRAE Standard 62.1 Acceptable Indoor Air Quality

Ventilation Requirements

ASHRAE Standard 62.1 outlines two procedures which can be used to evaluate whether a building is receiving the proper amount of ventilation. Calculations were performed according to the Ventilation Rate Procedure outlined in section 6 of the standard. The Ventilation Rate Procedure is a prescriptive procedure in which outdoor air intake rates are determined based on space type, occupancy level, and floor area. The appropriate design characteristics of each space were determined by referencing the construction documents; specifically the HVAC ductwork drawings, mechanical equipment schedules, and airflow flow diagrams. ASHRAE Standard 62.1 does not address laboratories in the detail required to maintain a safe working environment.

Compliance to The University of Pittsburgh's Laboratory Design Standard was also addressed in the discussion of appropriate ventilation rates.

The required ventilation rates per ASHRAE's Standard 62.1 have been met. For more information, see the *Design Considerations* subsection in the Existing Mechanical System Analysis, or refer to Appendix A.

LEED Analysis (Relevant Design Criteria)

The Salk Hall addition plans to apply for LEED certification after the construction process is significantly underway. There are two main categories under LEED for assessing the building's mechanical systems. They are Energy and Atmosphere and Indoor Environmental Quality. The Salk Hall addition will have to submit to the criteria established by LEED 3.0 in which there are 3 prerequisites for Energy and Atmosphere and there are 2 prerequisites for Indoor Environmental Quality. These prerequisites are mandatory benchmarks for sustainable design.

Energy and Atmosphere

- EA Prerequisite 2- is a design phase pre-requisite that mandates that the building has to meet the minimum energy performance which is outlined in EA Credit 1.
- EA Prerequisite 3- is also a design phase pre-requisite in which no CFC based refrigerants are to be used in the designed cooling equipment.
- EA Credit 2- requires on-site renewable energy. The Salk Hall Addition does not utilize renewable energy and therefore cannot receive any points for this credit.
- EA Credit 4- is enhanced refrigeration managements. The total refrigerant impact per ton must be less than 100.
- EA Credit 6- deals with buying green power from a utilities provider. The Salk Hall Addition receives its utilities from the University of Pittsburgh's central plants and therefore will not receive points for this credit.

Indoor Environmental Quality

- EQ Prerequisite 1- requires ASHRAE Standard 62.1 to be met for indoor air quality. The Salk Hall Addition will meet these criteria. It is important to keep in mind that the University of Pittsburgh has its own standard for acceptable air quality in laboratories and their support spaces. The rate of 8 air changes per hour has also been met.
- EQ Prerequisite 2- deals with environmental tobacco smoke control. The Salk Hall Addition is a non-smoking building.
- EQ Credit 1- deals with the monitoring of outdoor air delivered to the conditioned spaces. The credit requires that C02 monitoring must be done in every densely occupied space. This credit will not be met by the current design of the Salk Hall Addition.
- EQ Credit 2- is increased ventilation. The Salk Hall addition will most likely meet this requirement due to the high air change rates established by the University. While the addition will gain points in this category, the increased fan power will hurt the proposed case when it is compared to the baseline model required for EA Credit 1.
- EQ Credit 6.2- requires individual comfort control for 50% of the buildings occupants including multi-occupant spaces. This credit is met because each thermal zone is controlled by a thermostat and its own terminal VAV unit.
- EQ Credit 7.1- deals with the thermal comfort of the occupants. ASHRAE Standard 55-2004 is satisfied within the Salk Hall design.
- EQ Credit 7.2- is the verification of thermal comfort. This credit cannot be gained until a post-occupancy study is performed.

Existing Mechanical Systems

This system will review the current design of the Salk Hall Addition's HVAC system. Some design information may have changed since previous reports. The energy model, along with the load calculation, has been updated for the final report as well.

Major Design Considerations

Ventilation Requirements

Laboratories often have minimum air change rates associated with safety factors. These rates are influenced by the type of research expected to take place. The University of Pittsburgh's laboratory standard is 6-10 air changes per hour (ACH) while the zone is occupied and 4 ACH when the zone is unoccupied. The Salk Hall Addition includes a fume hood exhaust system. These local exhaust systems can be constant or variable volume and can be active intermittently throughout the day. Within the Salk Hall Addition, three air handling units supply the building with 87,000 CFM with the entire volume being outdoor air. The building was assessed per the Ventilation Rate Procedure according to ASHRAE Standard 62.1 and was determined to be within compliance. The calculations for the compliance of Standard 62.1 can be found in Appendix A. The TRACE 700 simulation of the BOD uses a ventilation rate of 8 air changes per hour during occupied periods, and 4 air changes per hour during unoccupied periods.

Table 1- BOD Airflow Summary

Air Handling Units and Total Airflow Rates (CFM)	
AHU-1	29,000 (100% OA)
AHU-2	29,000 (100% OA)
AHU-3	29,000 (100% OA)

One or more motion/infrared occupancy sensors will be installed to serve individual temperature-controlled zones. When a zone is determined by the sensors to be occupied, the lights of the zone will be switched on and the air system will be indexed to occupied set points. When the zone is determined to be unoccupied, the lights of the zone will be switched off and the air system will be indexed to unoccupied set points. Sensors will incorporate an adjustable delay to prevent too-frequent setting changes.

Internal Loads

Laboratories are filled with a variety of equipment that can add a sensible load to the space. These loads can be anywhere from 6-8 watts per square foot. These high internal loads, along with increased lighting loads for maximum visibility, call for year round cooling in many of the spaces within the Salk Hall Addition. An example of the peak internal loads summary, per TRACE 700, can be found in Appendix B.

Airside Design Information & Analysis

Interior and Exterior Design Conditions

The outdoor air design conditions used in the BOD for the Salk Hall Addition can be obtained in the ASHRAE Fundamentals Handbook. Summer design criteria for all areas will be 91°F dry bulb and 72°F wet bulb. The winter design criteria will be 3°F dry bulb as per the ASHRAE Fundamentals 0.4 / 99.6% condition for Pittsburgh, Pennsylvania. The summer ambient air design wet bulb temperature for the cooling towers will be 77°F. The table below describes the indoor design conditions for each type of space in the Salk Hall Addition. These are the same values that are utilized in the TRACE 700 simulation for the BOD.

Table 2-BOD Indoor Design Conditions

Indoor Design Conditions			
Room Type	**Summer Dry Bulb Temperature [°F]**	**Max. Summer Relative Humidity [%]**	**Winter DB [°F]**
Office/Meeting/Conference	72	50	72
Laboratories	72	60	72
Lab Support Rooms	72	60	72
Lab Personnel Corridors	72	60	72
Tele-Data Rooms	74	50	70
Linear Equipment Corridor	74	60	74

HVAC System Design Summary

Three identical 29,000 CFM air handling units, located within the mechanical penthouse, serve all conditioned spaces within the addition. The University's Laboratory Design Standards call for the use of 100% outdoor air units. Exhaust air will pass through each AHU's energy recovery wheel, exchange energy with the supply air, and discharge through roof mounted exhaust fans. Outdoor air will be drawn through wall louvers, on the north side of the building, into a double wall, accessible plenum as to serve the supply air intake requirements. There are 280 terminal units that support both supply and exhaust airflow services. This sum of units includes the Envirotec VAV boxes, fan powered boxes, and venturi style Phoenix control valves. The air handling units are comprised of the following components:

- Outdoor air intake plenum with an automatic isolation damper
- Filter section with MERV 7 (30%-efficient) 4-inch-deep pre-filters and
- MERV 14 (90%-efficient) 12-inch-deep final filters.
- Total heat energy recovery wheel section

- Steam preheat coil section
- Supply fan section with VFD (blow-through configuration)
- Sound attenuator section
- Humidifier section
- Chilled water cooling coil section (450 fpm maximum face velocity)

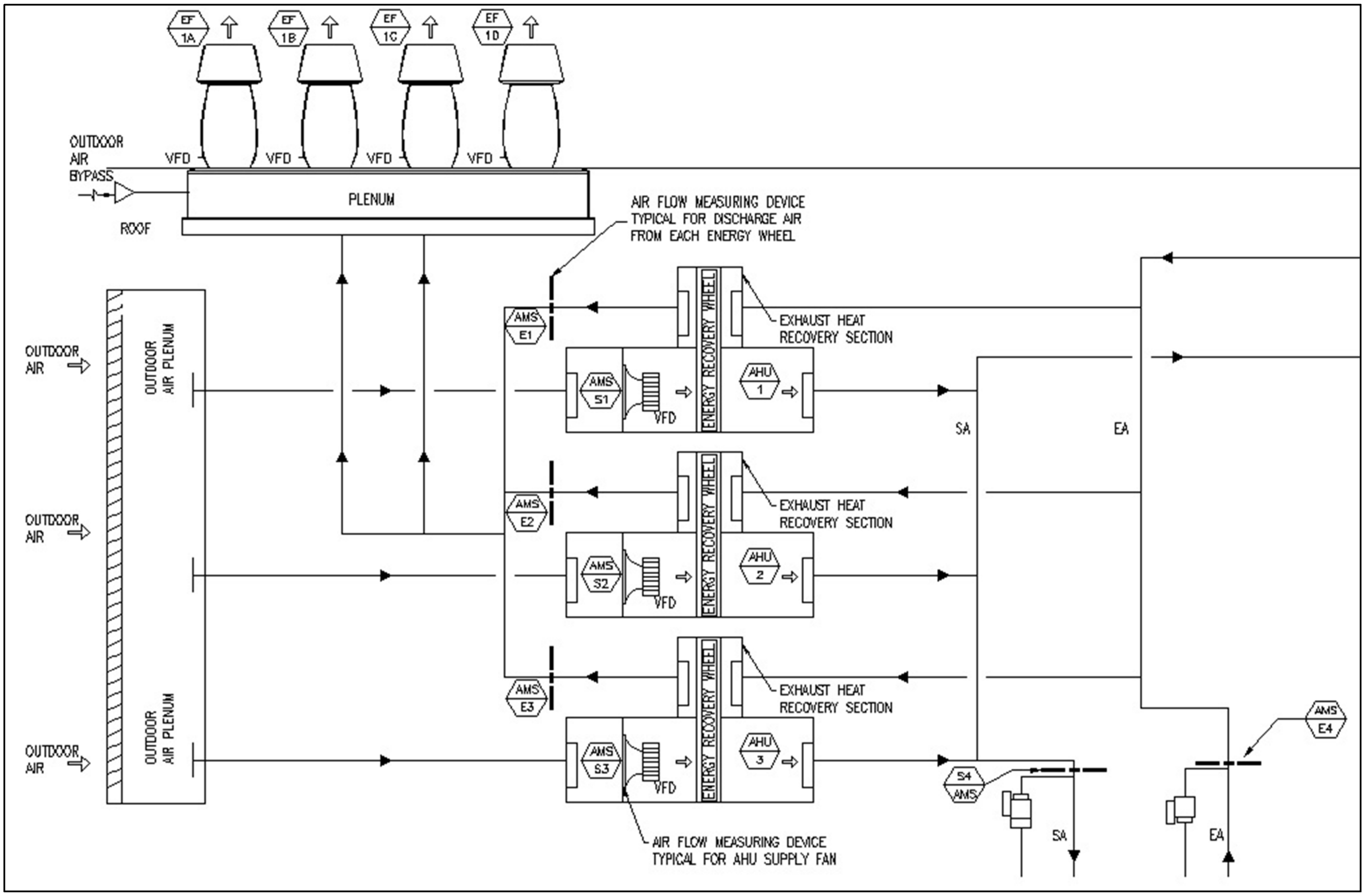
The following table, which excludes the supply fan in each air handler, summarizes the fan schedule for the Salk Hall Addition.

Table 3- BOD Fan Schedule

Fan Schedule			
Tag	**Type**	**Location**	**CFM**
EF-1A	Induced Flow	Roof	31500
EF-1B	Induced Flow	Roof	31500
EF-1C	Induced Flow	Roof	31500
EF-1D	Induced Flow	Roof	31500
SF-2	Propeller	Main Electric Room	10000
EF-2	Propeller	Main Electric Room	10000
SF-3	SWSI	Mechanical Level	10000
EF-4	Centrifugal	3rd Floor Roof	3000
EF-5	Propeller	Generator Room	3500
EF-6	Centrifugal	Roof	535
EF-7	Centrifugal	Roof	300

Figure 3 is an airflow diagram of the penthouse air handling units and their associated exhaust fans, which are located on the roof. The risers shown in the figure represent the supply and exhaust ductwork in the west shaft. This shaft exclusively services the laboratories and their support spaces. While both the shafts support laboratory spaces, the east shaft also serves the administrative and office spaces. Each shaft, as well as each air handling unit, is designed with an airflow measuring device to ensure design airflows are being met.

Figure 3-Airside Flow Diagram



Summary of Control Strategy

The laboratory's airflow control system was designed with Phoenix Controls' analog air valves with Automated Logic BAS DDC controllers, performing the laboratory airflow and temperature control. Phoenix Controls constant air volume air valves, provided with airflow feedback cards, will be utilized for fume hood exhaust service to maintain a constant face velocity across the fume hood opening. Phoenix Controls' variable air volume supply air valves, provided with airflow feedback cards, will be utilized to supply 100% OA makeup-air to the laboratory. These valves will be positioned to maintain airflow based on the total exhaust flow rate minus the room offset. The supply valves will be overridden to open further upon a need for more cooling or a ventilation purge of the laboratory. Phoenix Controls' variable air volume exhaust valves can also be overridden in case of an emergency.

Hydronic Systems Design Information & Analysis

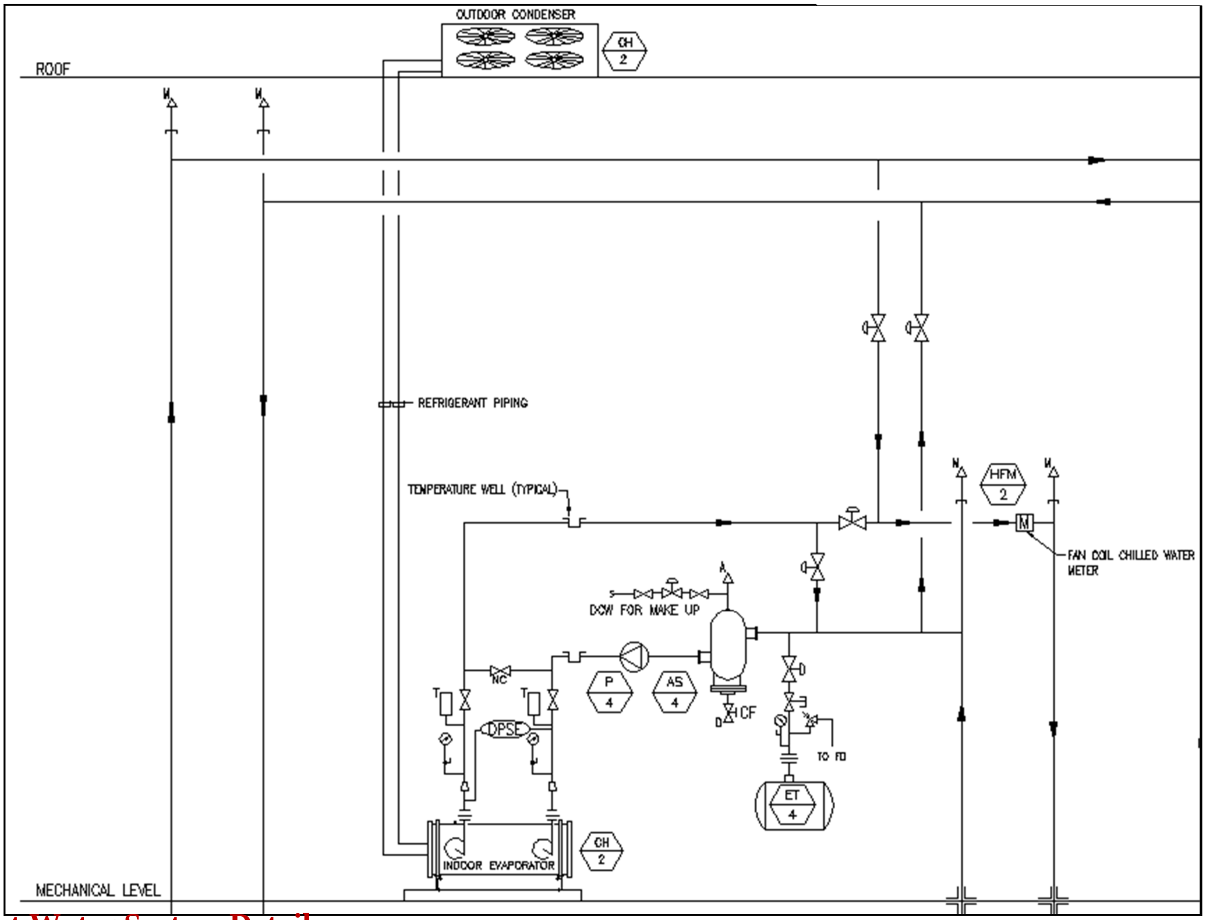
Chilled Water System Details

The building’s chilled water will be supplied by the Peterson Event Center chiller plant. 6” supply and return pipes will connect to the campus system adjacent to the Peterson Event Center plant. The P.E.C. chilled plant will be expanded as part of the project. The plant expansion will include a primary pump, 1200 ton chiller, and an 1100 ton cooling tower. The designed chilled water will be at a supply temperature of 42°F and a return temperature of 58°F. An increase in the chilled water supply temperature above 42 degrees may cause a room temperature excursion above the room temperature set-point. The designed condenser water supply temperature will be at 85°F while the return temperature is designed to be 95°F.

The Peterson Event Center houses both the cooling tower and water-cooled chiller associated with the Salk Hall addition. The cooling tower is of an induced draft design and processes 3000 gallons per minute. The designed entering water temperature is 90.6 degrees Fahrenheit and the design leaving temperature is 80.6 degrees Fahrenheit. The centrifugal chiller has a capacity of 1200 tons and uses R-123 as its refrigerant.

Figure 4 illustrates the chilled water loops between the penthouse level and the mechanical room on the first floor. The loop depicted in Figure 4 services the fan coil units’ chilled water demand in the linear equipment corridors, as well as the servicing the primary cooling coil in each air handling unit. The main supply and return risers, supplied by the campus loop, are on the west side of the diagram. The process chilled water system will be isolated from the campus system via a plate and frame heat exchanger. The system will have the capacity of supplying and returning temperatures between 55 °F and 65°F. Operational temperatures may be as high as 85 to 95 °F.

Figure 4-Split System Refrigeration



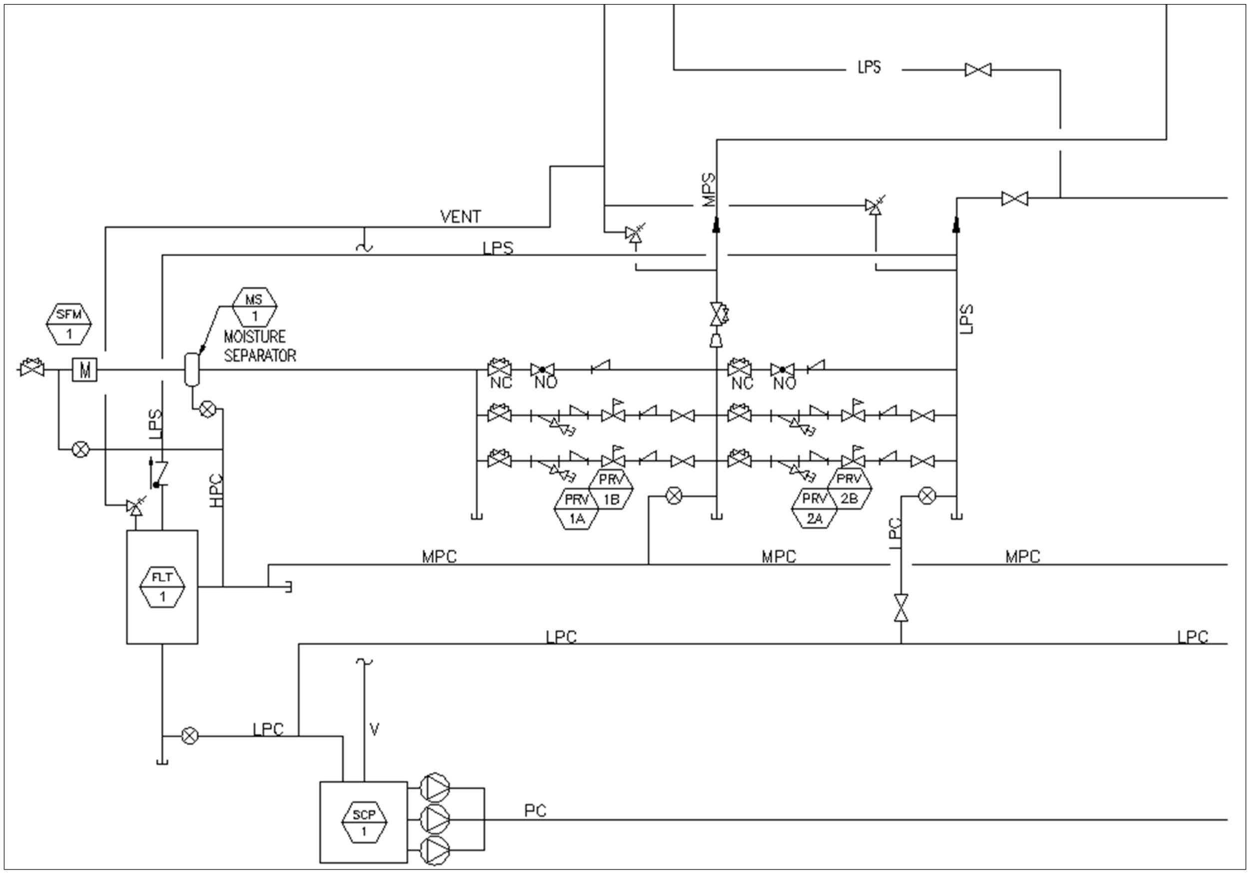
Hot Water System Details

The hot water heating system will consist of two shell-and-tube, LPS-to-hot water heat exchangers. Each heat exchanger will be sized for 100% of the load. Two primary system pumps will be provided, each with variable-frequency drive, and each sized for 100% of load. Variable frequency drives will maintain the differential pressure set point in the system. One or both pumps may operate to meet required capacities while attempting to operate under a condition for optimum energy performance. Multiple secondary loops will be provided for the perimeter radiation system. Each loop will consist of a 3-way mixing valve and hot water circulator pumps. This system will be constant volume.

Reheat coils and other heating equipment will be provided with modulating two-way control valves located on the return side of each coil. Terminal reheat valves will modulate to maintain room temperature at set point.

Figure 5 illustrates the process in which high pressure steam is undergoes a pressure reduction and is converted into medium and low pressure steam. Medium and low pressure condensates are also produced. The medium pressure stream is distributed to the sterilizers and glass cleaning equipment in the laboratories and their support spaces. The low pressure condensate is delivered to the heating coils and humidifiers. Low pressure steam is delivered to the laboratory hot water heaters, domestic hot water heater, and the shell and tube heat exchangers located in the first floor mechanical space.

Figure 5-Steam Pressure Reduction System



HVAC Pump Schedule

The following table outlines the HVAC pumps utilized by the Salk Hall Addition BOD.

Table 4-BOD Pump Schedule

HVAC Pump Schedule					
Tag	**Type**	**Location**	**GPM**	**Head**	**RPM**
P-1A	Base Mounted End Suction	First Floor	240	80	1750
P-1B	Base Mounted End Suction	First Floor	240	80	1750
P-2A	Horizontal Split Case	First Floor	600	70	1750
P-2B	Horizontal Split Case	First Floor	600	70	1750
P-3A	Base Mounted End Suction	Mechanical Level	70	80	1750
P-3B	Base Mounted End Suction	Mechanical Level	70	80	1750
P-4	Base Mounted	Mechanical Level	60	70	1750
P-5	Inline Split Coupled	First Floor	29	40	1750
P-6	Inline Split Coupled	First Floor	21	40	1750
P-7	Inline Split Coupled	First Floor	12	40	1750
P-11	Horizontal Split Case	P.E.C.	1920	45	1750

Additional Design Information

System Initial Cost

The estimated cost for the HVAC system in the Salk Hall Addition is about $3.5 million. This value would yield a unit cost of $43.15 per square foot. The estimated cost of the plumbing system is around $1 million. The estimated first costs of the HVAC and plumbing systems are $225,000 and $44,000, respectively. The total cost of the combined HVAC and plumbing systems is around 10.7% of the estimated total building cost.

Lost Space

The lost space due to mechanical systems is summarized in the following table. The first floor and the mechanical penthouse hold a majority of the HVAC and plumbing equipment. Shaft area was calculated on a floor-by-floor basis. The ducts were sized to yield a minimum duct construction cost, while still maintaining an appropriate aspect ratio.

Table 5- Lost Space Due to Mechanical Spaces

Mechanical Spaces			
Floor	**Lost Space (GSF)**	**Type**	**% Total**
1	1730	Equipment Room	20.00%
2	150	Shafts	1.70%
3	250	Shafts	2.90%
4	250	Shafts	2.90%
5	250	Shafts	2.90%
Penthouse	6000	Equipment Room	69.50%
Total	**8630**		100%

Energy Sources

The Salk Hall Addition receives its chilled water, processed steam, and electrical power from campus plants at the University of Pittsburgh. The following table outlines the rates delivered to Ballinger in 2008.

Table 6-Energy Generation Rates

Energy Generation Rates		
Type	**Rate**	**Units**
Electric	0.084	$/kWh
Steam	1.700	$/Therm
CHW	0.706	$/Therm

TRACE 700 Design Inputs and Assumptions (BOD)

Table 7-BOD TRACE Inputs and Assumptions

TRACE 700 Inputs and Assumptions for the BOD			
System Type	Variable Volume Reheat (30% Min Flow)	Utilities	CHW & Steam from Campus Plants
Energy Recovery	Total Energy Wheel	72% efficient sensible	70% efficient latent
Design SAT	54 °F	Min. Room RH	30%
Design CHW Temp	42 °F	CHW ΔT	16 °F
Supply Fan	0.004628 kW/CFM	Exhaust Fan	0.001058 kW/CFM
Fan Coil Units	Auxiliary Load	5.36324 kW Peak load	
Hot Water Pump Design Head	65 ft water	Purchased Chilled Water COP	1.0
Chilled Water Pump Design Head	70 ft water	Cooling Equipment Heat Rejection	Cooling Tower
DHW Load	1 Therm/Hr	Purchase District Steam Efficiency	95%
Weather Profile	Pittsburgh, PA TMY2	System Type	Dedicated OA
Control Strategies	The system is allowed to drift to a DB temp of 65°F from Midnight-6am. Utilization schedules have accounted for lighting loads, receptacle loads, and occupant density. Most pumps and fans are modeled with variable frequency drives.		
Perimeter Radiation Load	TRACE 700 cannot model multiple systems operating on the same zone. A system was created in TRACE to exclusively handling the perimeter radiation and radiant floor energy use. These design capacities were summed on a monthly basis, ratios were created for hours of use per month, and a peak load of 1253MBH was utilized. A utilization schedule for each month, requiring heating, was created with factors that would yield monthly demand totals within a 15% margin of the buildings actual monthly heating load. While the solution is not ideal, it is held constant through the comparisons.		
Dedicated OA	TRACE 700 is unable to model a 100% OA unit unless it is a dedicated ventilation unit. To curb this design limitation, the ventilation inputs under the airflow template allows for the selection of 100% OA. The ventilation load is set equal to the calculated cooling load. The VAV minimum is set as the ventilation rate for occupied hours. This strategy in turn forces TRACE 700 to treat the entire system as if it were 100% OA.		
Ventilation Rate	Labs: 8 ACH Occupied, 4 ACH Unoccupied	Non-Laboratory Spaces: Per ASHRAE 62.1 Guidelines	Schedules Based on Expected Hours of Occupancy and a utilization schedule dropping Lab Ventilation to 4ACH during unoccupied hours

Thermal Loads and Energy Use per TRACE 700

TRACE 700 outputs estimate that the operation of Salk Hall will cost **$520,762 per year**. The largest demand on the electrical system, relative to the HVAC system, is the energy required for fan operation. The ventilation requirement of Salk Hall's laboratories and their support spaces is the key factor which influences the high fan power demand. In the model, the supply fan delivers 90,794 CFM while the exhaust fans pull 101,057 CFM. The design for the Salk Hall Addition allows for 87,000 CFM of outdoor supply air.

Table 9 lists a few key load components; these load rates occur at the time of the cooling coil peak. TRACE 700's design cooling load summary for the Salk Hall Addition's BOD can be found in Appendix E.

Table 8-Peak Cooling Load Summary

Peak Cooling Load			
Calculated Cooling Load Type	**Total Load [Btu/h]**	**Calculated Cooling Load Type**	**Total Load [Btu/h]**
Solar Gain	203,811	Infiltration	523,865
Glass Transmission	37,805	Lights	272,000
Wall Transmission	61,443	People	264,767
Ventilation	1,789,294	Receptacle	806,001

The two largest loads are due to the high air change rates in the laboratories, as well as their high internal loads. These results are comparable to the energy model that Ballinger created within an acceptable range.

The following table is a breakdown of energy consumption by each respective piece of HVAC equipment. The demand for year round cooling can be directly attributed to the high internal loads of the laboratories.

Table 9-BOD Equipment Energy Summary

Equipment Energy Consumption			
Equipment	**Utility**	**Total Load**	**Peak**
Lights	Electricity	517,533 (kWh)	83.7 (kW)
Receptacles	Electricity	1,614,473 (kWh)	296.5(kW)
E.R. Parasitics	Electricity	3,504 (kWh)	0.4 (kW)
Cooling Coil Condensate	Recoverable Water	390.5 (1000/gal)	0.4 [1000gal/h]
DHW Load	Proc. Hot Water	8,760 (Therms)	1 (Therms/h)
Perimeter Radiation	Proc. Hot Water	19,479.8 (Therms)	9.3 (Therms/h)
Campus Chiller	Purchased Chilled Water	80,311 (Therms)	45.9 (Therms/h)
Cooling Tower	Electricity	87,076 (kWh)	37.1 (kW)
Cooling Tower	Make-up Water	4,283 (1000gal)	2.5 (1000gal/h)
Var. Vol. CHW Pump	Electricity	16,832 (kWh)	15 (kW)
Default Water Pump (HW)	Electricity	1,087 (kWh)	.2 (kW)
Boiler	Purchased Steam	53,099 (Therms)	74.9 (Therms/h)
Heating Water Circ. Pump	Electricity	100,561 (kWh)	11.5 (kW)
Condensate Return Pump	Make-up Water	3,162 (1000gal)	0.4 (1000gal/h)
Default Water Pump (CHW)	Electricity	37,870 (kWh)	4.3 (kW)
Supply Fan	Electricity	1,625,889.8 (kWh)	515.2 (kW)
Exhaust Fan	Electricity	441,294 (kWh)	129 (kW)

Operating Costs

The following table is derived from TRACE 700’s Energy Cost Budget summary.

Table 10-Energy Cost Budget for the BOD

TRACE 700’s Energy Cost Budget Output for the BOD			
Service	**Utility**	**Energy (10^6 BTU/h)**	**Peak (kBtuh)**
Lights	Electricity	1,766.3	286
Space Heating	Electricity	10.8	1
	Gas	0	0
	Purchased Steam	5,309.9	7,490
Space Cooling	Electricity	0.0	0
	Purchased CHW	8,031.2	4,588
Pumps	Electricity	533.6	106
Heat Rejection	Electricity	297.2	127
Fans	Electricity	7,055.3	2,199
Receptacles	Electricity	5,522.2	1,013
Total Building Consumption		**28,526.4**	

The following table is derived from TRACE 700’s Energy Cost Budget summary.

Table 11-BOD Yearly Operating Cost

TRACE 700’s Energy Cost Budget Output for the BOD		
Utility	**Energy (10^6 BTU/h)**	**$/year**
Electricity	15,185.4	$ 373,740
Gas	0.0	$ 0.0
Purchased Chilled Water	8,031.2	$ 56,754
Purchased Steam	5,309.9	$ 90,268
Total	**28,526**	**$ 520,762**

Emissions Estimate

The production of electricity yields emissions that are often harmful to the environment. In determining the total annual emissions due to the electricity consumption of the Laboratory, the total electrical energy demanded by the laboratory was multiplied by the lbm of pollutants per kWh. The largest pollutant created will be CO2 and its equivalent.

Table 12-Estimated Emissions per Year

Emissions Estimate		
Pollutant	**Eastern Emission Factors [lbm/kWh]**	**Per Salk Hall [lbm]**
CO_{2e}	1.74	7.74E+06
CO_2	1.64	7.30E+06
CH_4	3.59E-03	1.60E+04
N_2O	3.87E-03	1.72E+04
NO_X	3.00E-03	1.34E+04
SO_X	8.57E-03	3.81E+04
CO	8.54E-04	3.80E+03
TNMOC	7.26E-05	3.23E+02
Lead	1.39E-07	6.19E-01
Mercury	3.66E-08	1.63E-01
PM10	9.26E-05	4.12E+02
Solid Waste	2.05E-01	8.73E+05

The electrical demand on the campus utility plants is not known and therefore the plants' respective emissions cannot be calculated. However, regarding the addition's electricity use alone, the Salk Hall Addition is estimated to produce **16,003,220** pounds of pollutants per year.

Salk Hall has not yet been constructed and therefore no field data is available for comparison to the estimate.

Comparison of North West Laboratory Simulations

In order to establish an argument for potential variation in energy simulations results and their associated costs, the west laboratory on the third floor has been simulated using the 2009 ASHRAE RSTM Spreadsheet. The laboratory was selected due to its high internal loads, two exterior facing walls, and its 20 person occupant density. Identical design inputs and construction types were used in both the TRACE 700 simulation and the ASHRAE RSTM spreadsheet simulation. A major limitation of the RSTM spreadsheet is its inability to model ventilation loads. The thermal load calculated in the spreadsheet is based on solar thermal loads, internal heat gains, and the zone's occupant density. It is also important to keep in mind that the TRACE 700 simulation was also based on the RSTM method.

Table 13-ASHRAE RSTM Load Calculation vs. TRACE 700

ASHRAE RSTM vs. TRACE 700 Load Simulation			
Load	**TRACE OUTPUT**	**RSTM OUTPUT**	**% Difference (Trace to RSTM)**
Glass Solar	13,505 Btu/h	9,358 Btu/h	44 % Larger
Wall/Window Conduction	5,374 Btu/h	3,555.6 Btu/h	51 % Larger
Infiltration	8,771 Btu/h	7,689.4 Btu/h	14 % Larger
Lights	14,786 Btu/h	15,192.9 Btu/h	3 % Smaller
People	9,468 Btu/h	4853.7 Btu/h	95% Larger
Misc.	63,509 Btu/h	61,670 Btu/h	2.9 % Larger

It is unlikely that the north and west walls of the third floor laboratory receive 13,505 Btu/h with regards to a direct solar load, as per the TRACE simulation. This abnormal output was also noticed by Ballinger in the design process. Assuming the TRACE 700 simulation errors on the high-side, the BOD is sufficiently sized.

HVAC Re-Design

The following section details the re-design of the Salk Hall Addition's HVAC system. The cooling system is designed with dual wheel air handling units that supply neutral air to chilled beam terminal units for sensible cooling applications. A separate ventilation system has been incorporated to meet the laboratory air change requirements, as well as meet ASHRAE ventilation requirements. The system was analyzed by manipulating TRACE 700.

Supply Side Re-Design

Dual Wheel Energy Recovery

With the ample number of strategies available to recover heat and obtain higher energy efficiencies, it is hard to believe how many HVAC systems still utilize the traditional cool-and-reheat approach in order to address thermal comfort. These systems over-cool outdoor airstreams to a desired humidity level and then reheat the cooled air to a desired supply air temperature. While these traditional systems may have a lower first cost, more advanced designs yield lower annual operating costs and reduced emissions into the atmosphere.

Laboratories typically require high air change rates, with regards to the ventilation requirements, in order to maintain acceptable indoor environmental quality levels. Spaces with this type of load determining factor are known as "air-change driven" zones. This need for larger quantities of outdoor air, namely for ventilation purposes, gave way to the design of air handling units that produce "neutral" supply air. Neutral air refers to air that is slightly lower than room temperature but that has been dehumidified to maintain the relative humidity level in the building.[1] SEMCO's Pinnacle series (PVS) air handling units were selected for the Salk Hall Addition's re-design. The Pinnacle system incorporates strengths of passive total energy recovery, conventional cooling, and a passive dehumidification wheel to provide the best possible outdoor air preconditioning system. [2] The total energy wheel is to pre-condition the outdoor air by transferring heat from the building exhaust airflow to the incoming supply airflow. Both air streams are cleaned with a MERV-7 filter prior to their respective heat recovery functions. Next, the primary cooling coil and passive dehumidification wheel work in coordination to produce near room temperature supply air at very low humidity levels. The PVS' desiccant wheel incorporates a material that is optimized to remove moisture from a saturated airstream, without an active recovery source.

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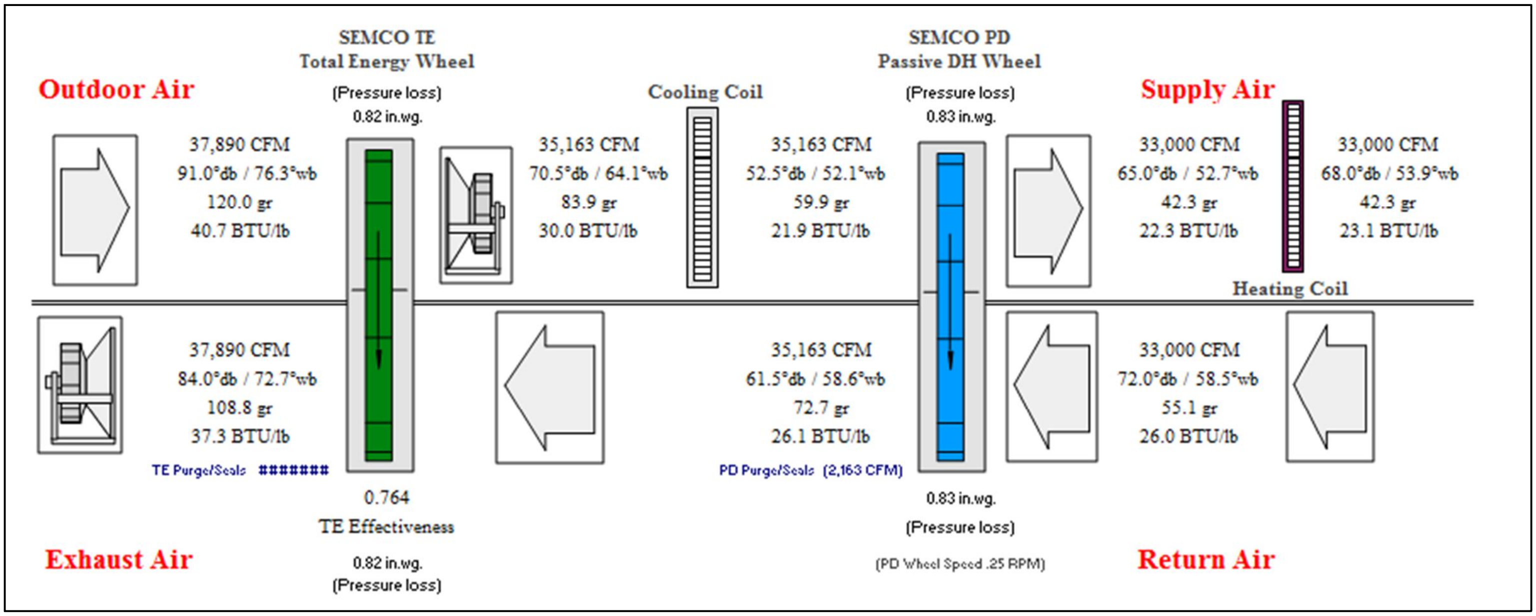
[1] Barnet, Barry M. "Chilled Beams for Labs"

[2] SEMCO. Pinnacle Series Design Guide

Dual wheel systems have the advantage of being able to respond to various combinations of temperature and humidity in an efficient manner, while still providing desired humidity levels that are well below that of the cool-and-reheat approach. The Pinnacle system is able to respond to varying conditions by modulating the rotational speed of the passive dehumidification wheel, and/or by adjusting the energy input to the cooling coil. The rotational speed control may be adjusted so as to control the level of temperature and moisture exchanged by the passive dehumidification wheel. The cooling control may be adjusted so as to control the level of cooling and dehumidification provided by the cooling coil. With these design capabilities, the Salk Hall Addition's re-design will be able to provide various combinations of supply air temperatures and humidity levels in order to maintain the desired psychometric set points for thermal comfort.

The following figure illustrates how the Pinnacle series air handling units condition outdoor air.

Figure 6-SEMCO PVS Air Handler Diagram



Two identical, 33,000 CFM Pinnacle Ventilation Units will be designed to handle the combined thermal and ventilation loads required by the Salk Hall Addition's design program. One unit will be exclusively handling the thermal comfort load by providing the chilled beams with neutral supply air. The other unit will provide 70°F supply air in order to supply the ventilation requirements of the Salk Hall Addition. The National Institute of Health requires that fume hood laboratories have back-up ventilation & exhaust systems. The AHUs are identical SEMCO PVS-

43 units, and in the case of a failure, the functioning air handler will service the ventilation system. Areas such as the linear equipment corridors, which have extremely high sensible loads, have been designed to incorporate auxiliary fan coil units in support of the main cooling system.

The PVS units provide supply air at the following conditions:

Table 14-Neutral Air Conditions

Neutral Air State Points	
Dry Bulb Temperature	68°F
Wet Bulb Temperature	54°F
Humidity	42.3 (Grains/Lb)
Relative Humidity	40%
Enthalpy	23 (Btu/Lb)

Figure 8 illustrates the processes the outdoor air undergoes on a psychometric chart.

Table 15-Psychometric Plot Key

Psychometric Chart Key	
Condition	**Description**
State 1 **(RED)**	Outdoor Air Design Condition
State 2 **(Green)**	Condition after Total Energy Wheel
State 3 **(Blue)**	Condition After Cooling Coil
State 4 **(Purple)**	Condition After Passive Desiccant Wheel
State 5 **(Maroon)**	Final Supply Air Condition after Heating Coil

Figure 7-Psychometric Plot of PVS AHU

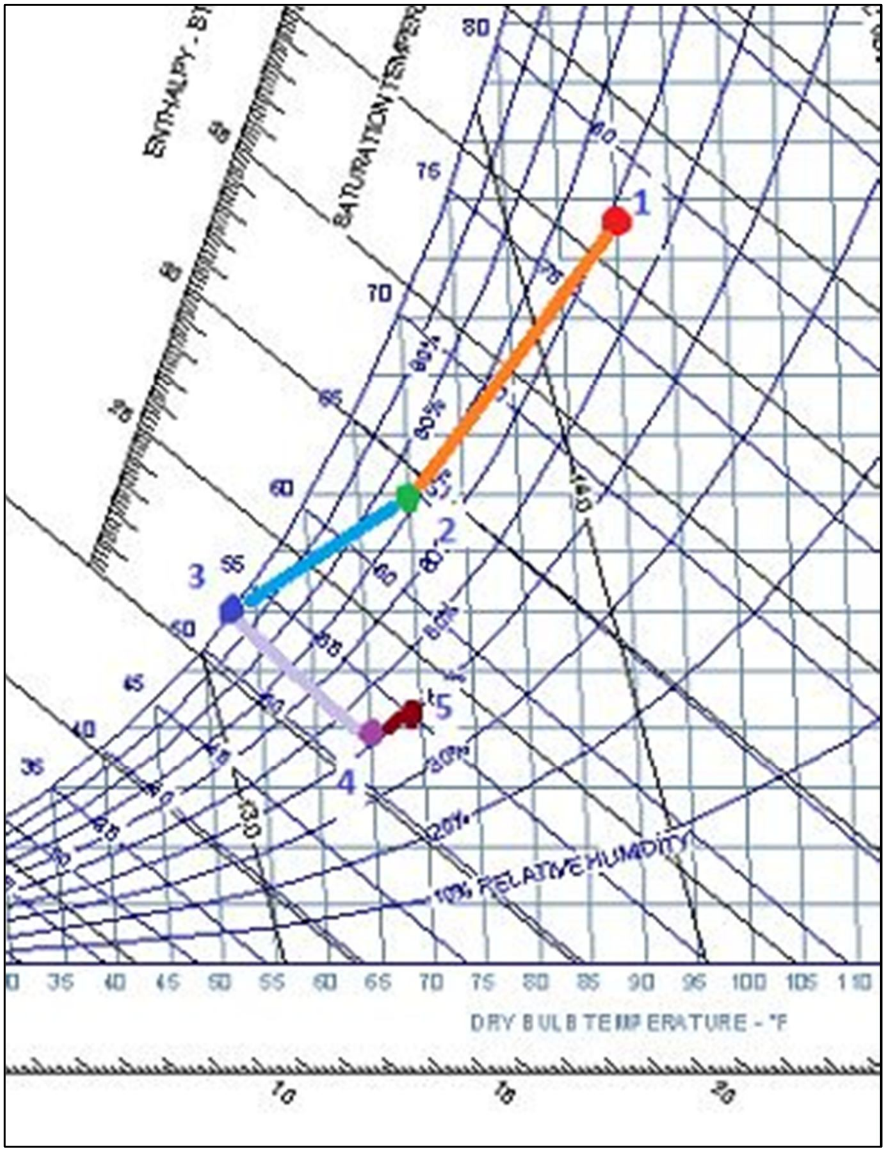
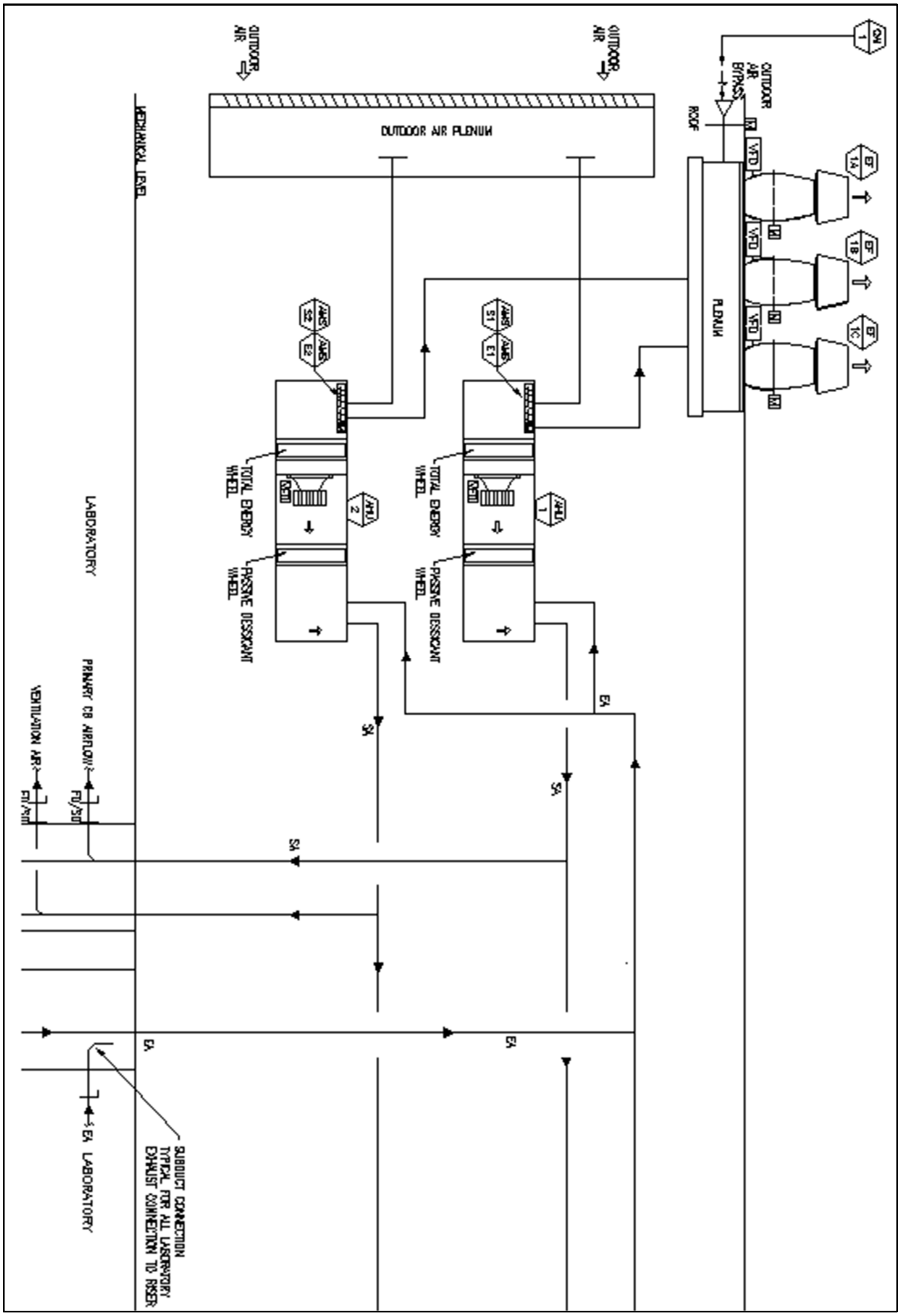


Figure 9 is the airflow flow diagram for the Salk Hall Addition's re-designed HVAC system.

Figure 8-Re-Design Airflow Flow Diagram



Demand Control Ventilation

Laboratories and vivarium facilities typically consume large amounts of energy and yield high carbon emissions due to the large volumes of outdoor air that needs to be conditioned, distributed, and exhausted from these facilities. Achieving the safe reduction or variation of air change rates in laboratories and vivariums can represent the greatest single approach for reducing these buildings' energy consumption and carbon foot print. As mentioned previously, the University of Pittsburgh has a ventilation design standard of 6-10 ACH for laboratories and their associated support spaces. The intent of this minimum ventilation rate is to rapidly clear a contaminated room of fugitive emissions, lab spills, and vapors generated by bench top lab work.[3]

A number of strategies have been attempted to curb the energy demand that coincides with high air change rates. Simply lowering the required ventilation rate is not a viable option in that high volumes of fresh air are required for dilution ventilation applications. Lowering the minimum ventilation rate during unoccupied periods also can be problematic. This strategy assumes that fugitive vapors only exist in the lab during occupied hours. Even with the incorporation occupancy sensors, a typical ventilation service can take near an hour to significantly reduce the ambient contaminant levels. This potentially leaves the occupant exposed to contaminants for an unacceptable duration of time.

The Salk Hall Addition's re-design will utilize a demand-based ventilation approach in which sensors will directly measure the quality of air. The sensors will detect contaminants such as volatile organic compounds (VOCs), ammonia, other chemical vapors, and particulates. If contaminant concentrations are at levels below a given threshold, the room is determined to be "clean." In this case, there is no need to increase the ventilation rate to further dilute clean air. When ventilation contaminants are sensed to be above the given threshold, ventilation rates are ramped accordingly in order to dilute the contaminants. When attempting to determine an appropriate airflow rate for purging a contaminated area, it becomes clear no set standard exists. A study presented at the 2009 Winter ASHRAE conference showed a greater than 10-1 reduction

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[3] Sharp, Gordon P. "Demand-Based Control of Lab Air Change Rates"

in lab room background concentrations resulted from increasing the air change rate from 4 to 8 ACH. [4]

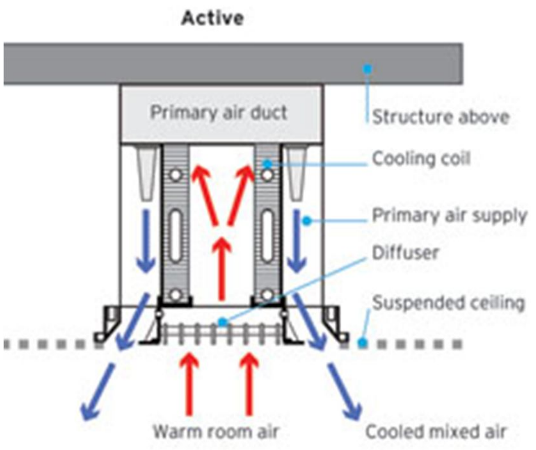
Table 16-Re-Design Ventilation Rates

Ventilation Rates for the Salk Hall Addition's Re-Design		
Space Type	**Ventilation Airflow Requirement**	**Comments**
Laboratories/Support Spaces	4 ACH with the capability of purging the laboratory spaces with a rate of 8 ACH	4 ACH 24/7 in Laboratory Spaces
Non-Laboratory Spaces	Per ASHRAE Standard 62.1	See Appendix A

Aircuity's "Smart Lab" Demand Control Ventilation for Research Areas system will be the sensor packaged incorporated in the re-design.

Active Chilled Beams

Figure 9-Active Chilled Beam Diagram



The Salk Hall re-design utilizes active chilled beams to meet the sensible cooling loads within each space. Neutral air, at 68°F, is introduced into each beam as the primary airflow. This primary air expresses through the beam and consequently induces room air inside the beam. This mixture of primary air and room air is then cooled and diffused out linear slots. This process is diagramed in Figure 11. Two critical performance characteristics need to be addressed when considering the implementation of chilled beams. The first is using warmer than normal chilled water supply temperatures and the second is the necessity to constantly maintain the humidity level in the conditioned space. If standard 45°F chilled water is utilized in chilled beams, there is a high potential for condensing on the coil in the beam. In order to avoid this condition, the room humidity must be maintained below a dew point temperature of 55°F. [5] In the Salk Hall Addition's re-design, the chilled water supply temperature is 52°F. The

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[4] Sharp, Gordon P. "Demand-Based Control of Lab Air Change Rates"

[5] Rumsey, Peter. "Chilled Beams in Labs: Estimating Reheat and Saving Energy on a Budget"

re-design will be utilizing different thermostat set point in order to meet thermal comfort requirements.

Table 17-Re-Design Indoor Design Conditions

Re-Design: Indoor Design Conditions			
Room Type	**Summer Dry Bulb Temperature [°F]**	**Summer Relative Humidity [%]**	**Winter DB [°F]**
Office/Meeting/Conference	72	45	72
Laboratories	72	45	72
Lab Support Rooms	72	45	72
Lab Personnel Corridors	72	45	72
Tele-Data Rooms	74	45	70
Linear Equipment Corridor	74	50	74

Make-Up Ventilation System

The Salk Hall re-design incorporates two identical SEMCO PVS air handling units in order to supply two separate services: a thermal comfort system and dedicated ventilation system.

The dedicated ventilation unit was designed to meet the combined make-up ventilation requirements of each conditioned space. The make-up ventilation rate for each space was determined by taking the minimum required ventilation rate and subtracting out the primary airflow being constantly delivered to the chilled beams.

The make-up ventilation system utilizes a typical variable air volume strategy in the non-laboratory spaces. The BOD for the Salk Hall Addition included the Envirotec SDR VAV terminal to serve non-laboratory spaces. It has been included in the re-design as well. The Envirotec SDR incorporates Envirotec's patented FlowStar airflow sensor. Most differential pressure sensors provide a signal equal to 1.5 times the equivalent velocity pressure signal. The FlowStar provides a differential pressure signal that is 2.5 to 3 times the equivalent velocity pressure signal. This amplified signal allows more accurate and stable airflow control at low airflow capacities. Low airflow control is critical

Figure 10-Phoenix Venturi Air Valve

for maintaining indoor air quality, minimizing reheat applications, and preventing over cooling during light loads.[6] In the BOD, the SDR units were installed with reheat coils. The Salk Hall re-design will not be utilizing any reheat coils in any of its HVAC systems.

The laboratory spaces will utilize Phoenix Accel II Airflow Control Valves to regulate the amount of ventilation air delivered to each zone. Unlike a terminal box, Phoenix control valves do not attempt to measure airflow. Rather, they rely on an airflow characterization curve that is installed into every valve prior to its arrival on site. Once installed, the valve will already know where to set the damper for any specified flow within its design range. Once an airflow control device is installed in a ductwork system, it will need to respond to constant changes in duct static pressure. A typical terminal box does this by continuously measuring the velocity pressure and then reacting by commanding the actuator to a new position to maintain flow. The terminal box requires long, straight runs of ductwork before and after, for the transducer, or measuring device to produce accurate airflow measurements. The result of this is additional expense and complexity. The Accel II venturi valve adjusts and compensates for fluctuations of duct pressure by using a mechanical pressure-independent cone and spring assembly that moves in and out of the venturi orifice, increasing and decreasing the airflow in a very predictable manner when exposed to pressure drops within a specified range. It’s this pressure independent cone assembly that dictates what minimum static pressures are required to operate properly.[7] These control valves will be utilized in the laboratory in order to ensure airflow directions are maintained with in the re-design’s ductwork system. The phoenix control valves will be used on the exhaust side for the laboratories as well.

Design Summary & Control Strategy

The re-design of Salk Hall’s HVAC system had two main design intents: maintain indoor environmental quality and to provide appropriate indoor design conditions to ensure thermal comfort. The basis for the re-design was the requirements set forth by ASHRAE Standard 62.1 and the University of Pittsburgh’s laboratory standards. The main consideration was the ventilation requirement to each space. The second factor that influenced the re-design was the fact that chilled beams only provide sensible cooling to a space. This means that the primary air delivered to each terminal unit must be of an appropriate moisture content to dehumidify the

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[6] Envirotec SDR Catalog

[7] Phoenix Controls Website: Valves Product Information

space. When determining the amount of primary airflow required to each space, the peak latent loads for each space were utilized to determine appropriate flow rates through the following equation.

$$CFM_L=Q_{Latent}/(4840*(W_{room}-W_{supply})$$

CFM_L= CFM Required to Meet Latent Load [CFM]
Q_{Latent}= Peak Latent Load per Space [Btu/h]
W_{Room}= Humidity Ratio of the Room [Lb/Lb]
W_{Supply}= Humidity Ratio of Supply Air [Lb/Lb]

After the primary airflow requirement to each space was determined, chilled beams were selected on the volume of primary airflow they could support. The number of beams per space was determined by considering the required amount of primary airflow as well as the required design capacity to meet sensible cooling load. The calculations included in Appendix C are based off data published in TROX's DID-632 catalog. The appropriate correction factors were included to account for differences in flow rates as well as varying temperature differentials. The Salk Hall re-design utilizes 237 chilled beams.

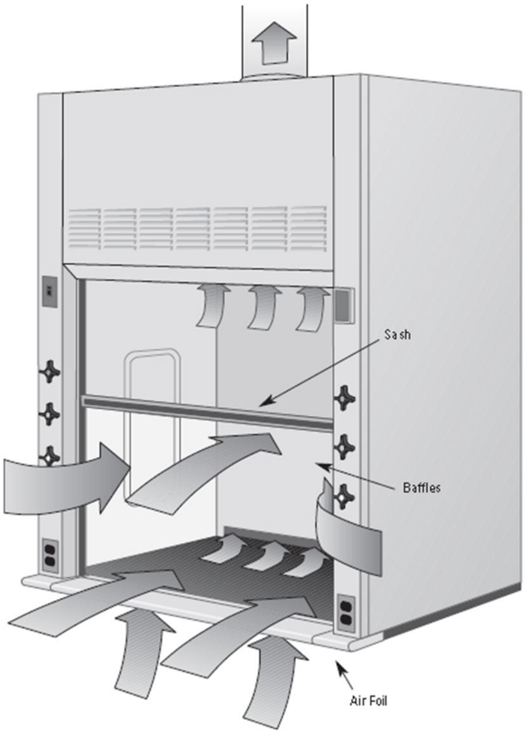
The ventilation system of the Salk Hall re-design incorporated a number of notable design concepts. A demand controlled ventilation system has been incorporated in the re-design allowing the amount of ventilation airflow delivered to the laboratories and their support spaces to be greatly reduced. The system monitors the concentration levels of particulates and contaminants in the laboratories and reports back to its controller. If the air is determined to be of an appropriate indoor environmental quality level, no action is necessary. If the air is determined to be contaminated, the system flushes the laboratories and their support spaces with a ventilation rate of 8 air changes per hour. This purge is intended to dilute the contaminants and allow them to be exhausted out of the building. The system utilizes to types of variable air volume terminals. The laboratories maintain airflow with Phoenix's Accel II control valves. Theses venturi valves are pressure independent and ensure that airflow does not travel the wrong way within the duct system. These valves are more expensive that the Envirotec SDR terminal VAV unit that is used in office and administrative spaces. Theses boxes measure airflow through a set of sensors in each unit and adjust their respective dampers accordingly.

Exhaust System Re-Design

Low Flow vs. Low Velocity Fume Hoods

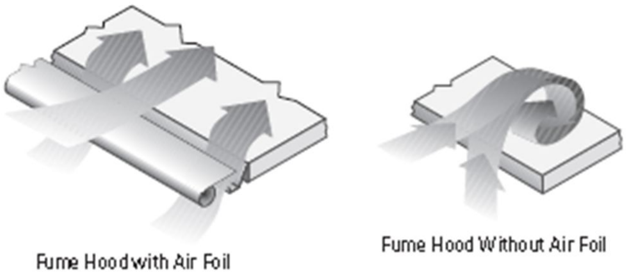
The complexities of fume hood operation become clear when examine all the airflow dynamics that affect the zone immediately surrounding the hood. An adequate "pull" is required to move fumes from the fume hood through the duct work. Face velocity is measured in feet per minute at the vertical sash plane. This constant face velocity is maintained by regulating exhaust airflow rate. It is also important to include an airfoil in the design of fume hoods. This decreases the turbulence of the airflow as it enters the hood.

Figure 11-Fume Hood Diagram



A low flow fume hood is one that has had the exhaust volume reduced by operating through a smaller sash opening. These types of hoods do not require the containment to be the same with the sash full open for the setup as it is for usage. While energy savings can parallel that of low velocity hoods, the sash position must constantly be managed which can be a distraction to the user. Low velocity fume hoods also achieve energy savings by reducing the operating sash opening and corresponding exhaust volume. A low velocity hood and a low flow hood differ in that a low velocity hood can maintain appropriate capture rates. Low velocity fume hoods can maintain this capture rate at face velocities as low as 60 feet per minute.

Figure 12-Airfoil Airflow Patterns

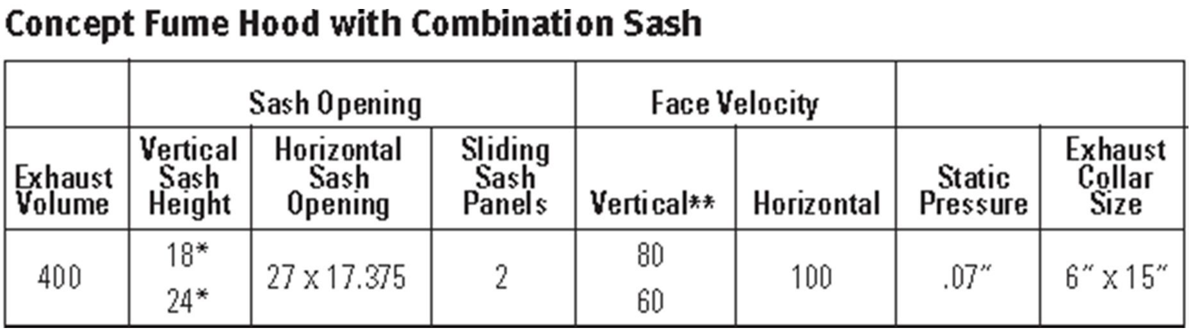


All VAV systems should be used with a restricted bypass fume hood. This is due to the fact that only the amount of air needed to maintain the specified face velocity is pulled from the room. This yields significant energy and cost savings. Key design considerations include locating diffusers at least 4 feet away from the hood, avoiding the use of 2’x2’ diffusers, and providing no more than 400 CFM through the diffusers near the hoods.

The University of Pittsburgh also has its own set of standards with regards to fume hood design. The University requires all hoods to be variable volume systems with face velocities of 100 feet per minute. The design memorandum, delivered to Ballinger on March 31st, 2010, states that fume hood face velocities may be lowered based on ASHRAE 110 tests. The re-design will assume that Hamilton Lab’s Concept fume hood will meet the requirements of the ASHRAE test.

Hamilton Lab’s Concept fume will meet all the requirements set forth in the design intent. The following table summarizes its technical details.

Table 18-Hamilton lab’s Concept Fume Hood Design Data



Concept Fume Hood with Combination Sash

	Sash Opening			Face Velocity			
Exhaust Volume	Vertical Sash Height	Horizontal Sash Opening	Sliding Sash Panels	Vertical**	Horizontal	Static Pressure	Exhaust Collar Size
400	18* 24*	27 x 17.375	2	80 60	100	.07″	6″ x 15″

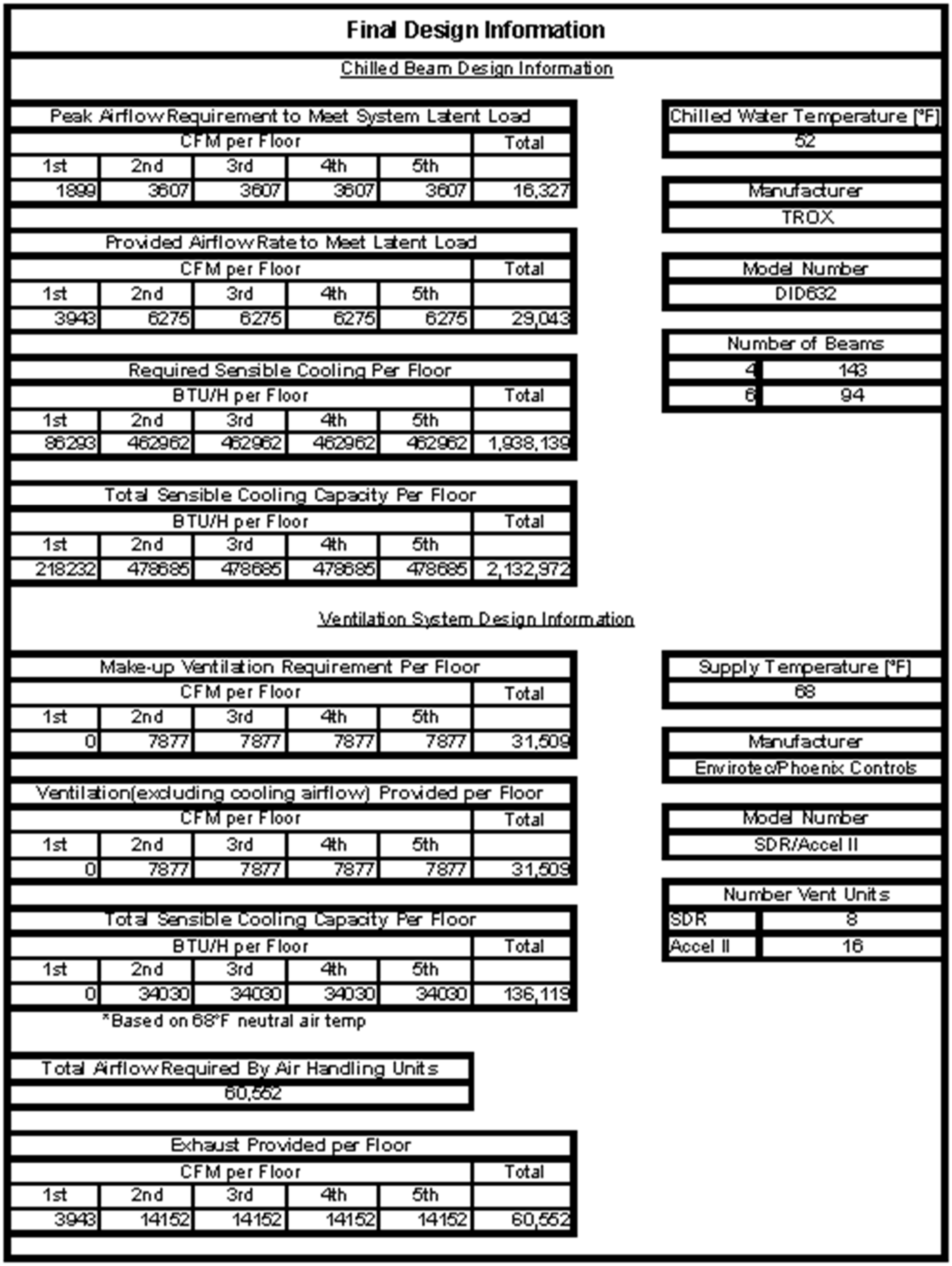
High Plume Dilution

The main objective of a laboratory exhaust system is to remove hazardous or noxious fumes from a laboratory, dilute the fumes as much as possible, and expel them from the building so that the fumes do not contaminate the rood area not the area near the outdoor air intakes. For this reason, Greenheck’s Vektor-MD Mixed Flow exhaust fan will be utilized. The Vektor-MD uses a roof mounted inline blower to exhaust and dilute the re-design’s laboratory spaces. The Salk Hall re-design will utilize a triple unit system.

Figure 13-Vector MD Tri-Unit

Airside Design Summary

Table 19-Airside Design Summary



Final Design Information

Chilled Beam Design Information

Peak Airflow Requirement to Meet System Latent Load					
CFM per Floor					Total
1st	2nd	3rd	4th	5th	
1899	3607	3607	3607	3607	16,327

Provided Airflow Rate to Meet Latent Load					
CFM per Floor					Total
1st	2nd	3rd	4th	5th	
3943	6275	6275	6275	6275	29,043

Required Sensible Cooling Per Floor					
BTU/H per Floor					Total
1st	2nd	3rd	4th	5th	
86293	462962	462962	462962	462962	1,938,139

Total Sensible Cooling Capacity Per Floor					
BTU/H per Floor					Total
1st	2nd	3rd	4th	5th	
218232	478685	478685	478685	478685	2,132,972

Chilled Water Temperature [°F]
52

Manufacturer
TROX

Model Number
DID632

Number of Beams	
4	143
6	94

Ventilation System Design Information

Make-up Ventilation Requirement Per Floor					
CFM per Floor					Total
1st	2nd	3rd	4th	5th	
0	7877	7877	7877	7877	31,509

Ventilation(excluding cooling airflow) Provided per Floor					
CFM per Floor					Total
1st	2nd	3rd	4th	5th	
0	7877	7877	7877	7877	31,509

Total Sensible Cooling Capacity Per Floor					
BTU/H per Floor					Total
1st	2nd	3rd	4th	5th	
0	34030	34030	34030	34030	136,119

*Based on 68°F neutral air temp

Total Airflow Required By Air Handling Units
60,552

Exhaust Provided per Floor					
CFM per Floor					Total
1st	2nd	3rd	4th	5th	
3943	14152	14152	14152	14152	60,552

Supply Temperature [°F]
68

Manufacturer
Envirotec/Phoenix Controls

Model Number
SDR/Accel II

Number Vent Units	
SDR	8
Accel II	16

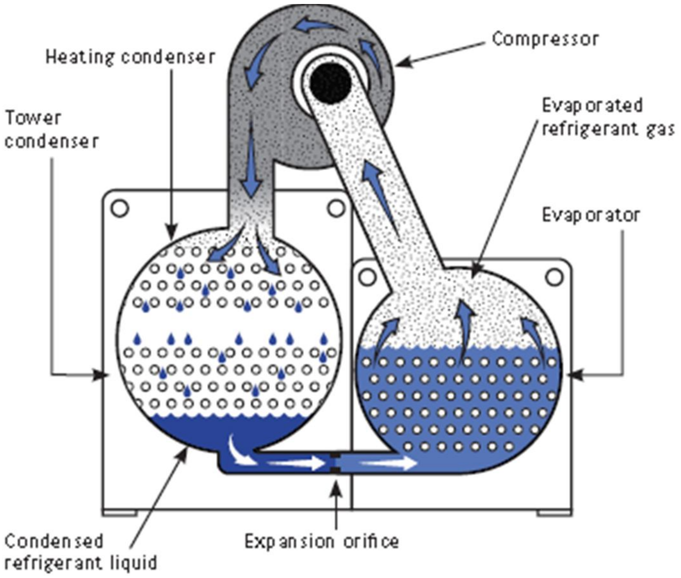
Hydronic System Re-Design

Salk Hall receives its chilled water and steam from campus plants at the University of Pittsburgh. The re-design will be utilizing a heat recovery chiller along with a condensing boiler in order to meet the demands of the water-side systems. Aside from individual process loads, no campus steam will be used in the re-designed HVAC system.

Design Intent

The implementation of small screw or scroll compressors, which can produce water temperatures as high as 140°F, led to the opportunity to recovery this heat by utilizing a heat recovery chiller. These systems are called "dedicated" heat recovery because 100% of the heat generated by the DHRC can be used for hot water applications.[8] Heat recovery chillers provide an efficient answer to simultaneous heating and cooling loads. Since Salk Hall has a year-round demand for cooling, a heat recovery chiller and a condensing boiler have been implemented in the re-design.

Figure 14-Double Bundle Heat Recovery Chiller



Recovered heat can be used in domestic water systems, air-handling equipment, or re-heat applications. The ability to adjust the condenser water temperature to fit any of these heat recovery applications requires a chiller separate from the main chiller plant for the greatest efficiency. The combination of a dedicated heat recovery chiller and a high efficiency primary chiller, while operating at the highest condenser water temperatures allowed by ambient conditions, allows beneficial loading of the heat recovery chiller to serve heating loads, while the remainder of the cooling load is served by the more efficient main chillers.[9]

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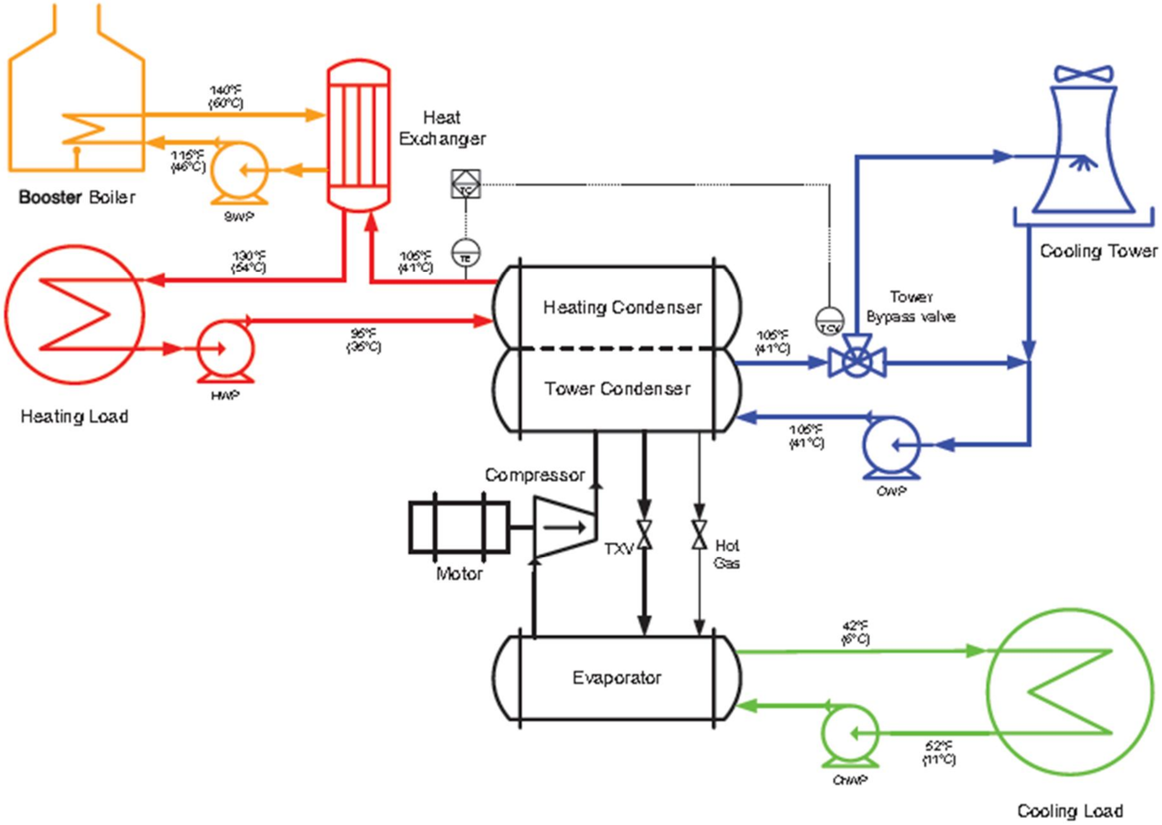
[8] Durkin, Thomas. "Dedicated Heat Recovery"
[9] Durkin, Thomas. "Dedicated Heat Recovery"

Double-Bundle Condenser Heat Recovery

The double-bundle method of condenser heat recovery can reduce the amount of energy consumed for heating in chilled-water applications. It adds a second heat-recovery condenser to collect heat that normally would be rejected to the cooling tower by the cooling condenser. The collected heat is then used to heat water for domestic use, comfort heating, or a process application.[10]

The figure below illustrates a typical chilled-water plant equipped to satisfy concurrent cooling and heating loads.

Figure 15-Typical Chilled Water Plant to Meet Simultaneous Heating and Cooling Loads



When a heating load exists, water flows through the cooling condenser and is adjusted so that the chiller rejects less heat to the cooling tower. Flow modulation is accomplished with a variable-frequency drive on the condenser. As the water temperature returning from the heating load falls, the variable-frequency drive modulates the condenser-water pump to decrease the flow of water through the cooling condenser and tower. With less heat rejected outdoors, more heat can be

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[10] Rand, Ingersoll. "Heat Recovery Chiller in Trace"

collected by the heat-recovery condenser. The heat recovery condenser would ideally produce a leaving temperature of 130 °F.

Johnson control's York Model YK Heat Recovery Chiller was selected for the re-design. Figure 20 outlines the chiller's specifications.

Condensing Boilers

A condensing boiler saves energy by reducing hot water system design temperatures. For many years, the minimum allowable temperature for gas-fired , hot water boilers was around 140°F, and any temperature less than that would cause condensing and corrosion within the boilers. The dew point for the flue gases from the combustion of natural gas is around 135°F, depending on the amount of methane.[11] These flue gases contain carbon dioxide and water vapor and if mixed with water vapor will form carbonic acid in cast-iron and steel boilers. The result is corrosion of the tubes and flue collector. This often would yield hot water supply temperatures as high as 240°F.

Condensing boilers are designed to use condensing as means of achieving higher thermal efficiencies. The maximum efficiency for a non-condensing boiler is around 87% with careful control of the percentage of excess air required for clean combustion. Condensing boilers are configured to accept condensation without damage, and without them supply temperatures as low as 130°F. Condensing boilers are more expensive boilers. Aside from their ability to save energy, there are a number of favorable design characteristics with the use of a condensing boiler. The piping is much simpler since there is no need for warm-up procedures that non-condensing boilers require. This procedure often includes a variety of equipment such as primary pumps, a primary by-pass, and a secondary three-way valve.

While operating with low hot water temperatures is advantageous, the temperature range of 80°F to 140°F is ideal for the amplification of legionella bacteria. To minimize the risk to service personnel, it is recommended a biocide by added to these water systems.[12] The re-design will assume that these agents have been added.

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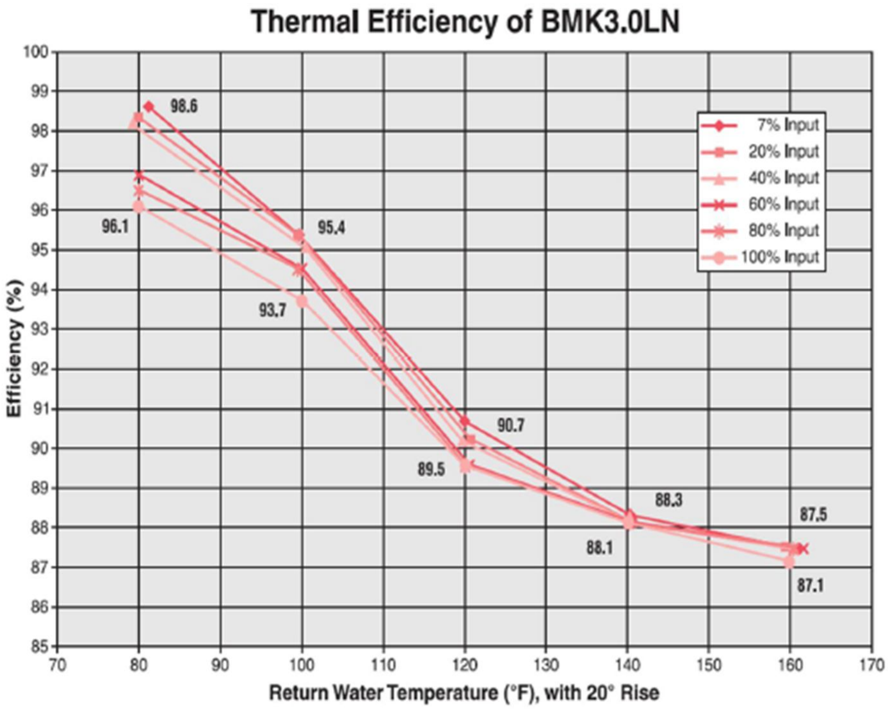
[11] Rishel, James B. "Reducing Energy Costs With Condensing Boilers & Heat Recovery Chillers"

[12] Rishel, James B. "Reducing Energy Costs With Condensing Boilers & Heat Recovery Chillers"

Aerco's Low NOx BMK3.0 condensing boiler has been selected for the re-design. Its efficiency peaks at 98.6% when operating with an inlet temperature of 80 °F.

Figure 16- Thermal Efficiency of BMK3.0



TRACE 700 Design Inputs and Assumptions (Re-Design)

Table 20-Re-Design TRACE Inputs and Assumptions

TRACE 700 Inputs and Assumptions for the Re-Design			
System Type	Active Chilled Beam with Dual Wheel Energy Recovery	**Utilities**	Electricity Natural Gas
Energy Recovery I	Total Energy Wheel	76% Total Efficiency	
Energy Recovery II	Passive DH Wheel	Leaving Humidity Ratio of 42.3 gr/lb.	
Design SAT	68°F	**Min. Room RH**	30%
Design CHW Temp	52°F	**CHW ΔT**	16 °F
Supply Fan	0.000825 kW/CFM	**Exhaust Fan**	0.0.000946 kW/CFM
Fan Coil Units	Auxiliary Load	5.36324 kW Peak load	
Hot Water Pump Design Head	65 ft water	**Heat Recovery Chiller**	Reject Condenser Heat Into Heating Plant @ 110°F
Chilled Water Pump Design Head	80 ft water	**Cooling Equipment Heat Rejection**	Cooling Tower
DHW Load	1 Therm/Hr	**Condensing Boiler Efficiency**	97%
Condensing Boiler Supply Temperature	140°F	**Condensing Boiler Return Temperature**	90°F
Weather Profile	Pittsburgh, PA TMY2	**System Type**	Dedicated OA
Control Strategies	The system is allowed to drift to a DB temp of 65°F from Midnight-6am. Utilization schedules have accounted for lighting loads, receptacle loads, and occupant density. Most pumps and fans are modeled with variable frequency drives.		
Perimeter Radiation Load	TRACE 700 cannot model multiple systems operating on the same zone. A system was created in TRACE to exclusively handling the perimeter radiation and radiant floor energy use. These design capacities were summed on a monthly basis, ratios were created for hours of use per month, and a peak load of 1253MBH was utilized. A utilization schedule for each month, requiring heating, was created with factors that would yield monthly demand totals within a 15% margin of the buildings actual monthly heating load. While the solution is not ideal, it is held constant through the comparisons. The condensing boiler		
Separate Services	TRACE 700 does not realistically model the energy use of active chilled beams. In order to accurately model the air side energy use, TRACE 700's inputs again had to be manipulated. Each zone in the model has a pre-set cooling CFM that is equal to the primary airflow volume required by the chilled beam calculations in Appendix C. Each room also has a constant ventilation airflow rate that is based on the make-up air calculations in Appendix D. Two identical fans are modeled for the two supply services. In order to account for the chilled water load, the TRACE 700 fan coil unit system was used on a room by room basis. This will provide the most accurate simulation to determine the HVAC systems energy efficiency.		
Ventilation Rate	Labs: 4 ACH (Sized for 8ACH if Req.)	Non-Laboratory Spaces: Per ASHRAE 62.1 Guidelines	

Energy Use per TRACE 700 (Re-Design)

TRACE 700 outputs estimate that the operation of the Salk Hall Addition will cost **$302,659** per year. The largest demand on the electrical system, relative to the HVAC system, is the energy required for fan operation. The ventilation requirement of Salk Hall's laboratories and their support spaces is the key factor which influences the high fan power demand. In the model, the supply fan delivers 60,254 CFM while the exhaust fans pull 71,119 CFM. The re-design for the Salk Hall Addition allows for 66,000 CFM of outdoor supply air.

The following table is a breakdown of energy consumption by each respective piece of HVAC equipment. The demand for year round cooling can be directly attributed to the high internal loads of the laboratories.

Table 21- Equipment Energy Summary (Re-Design)

Equipment Energy Consumption			
Equipment	**Utility**	**Total Load**	**Peak**
Lights	Electricity	517,533 (kWh)	83.7 (kW)
Receptacles	Electricity	1,614,473 (kWh)	296.5(kW)
Cooling Coil Condensate	Recoverable Water	3.9 (1000/gal)	0.0 [1000gal/h]
DHW Load	Proc. Hot Water	8.8 (Therms)	
Perimeter Radiation	Proc. Hot Water	19,479.8 (Therms)	9.3 (Therms/h)
HR Chiller	Electricity	604,556 (kWh)	82.1 (kW)
Cooling Tower	Electricity	20,116.1 (kWh)	2.8 (kW)
Cooling Tower	Make-up Water	1,249.1 (1000gal)	0.2 (1000gal/h)
Var. Vol. CHW Pump	Electricity	9,706 (kWh)	1.1 (kW)
Var. Vol. Cond Pump 2	Electricity	10,958.5 (kWh)	1.3 (kW)
Control Panel for HRC	Electricity	8760 (kWh)	1.0 (kW)
Default CHW Water Pump	Electricity	124 (kWh)	0.0 (kW)
Condensing Boiler	Gas	20, 451.7 (Therms)	13.9 (Therms/h)
Heating Water Circ. Pump	Electricity	27,779 (kWh)	3.2 (kW)
Default HW Pump	Electricity	10, 461 (kWh)	1.2 (kW)
Supply Fan	Electricity	627,700 (kWh)	73.1 (kW)
System Exhaust Fan	Electricity	674,335 (kWh)	102.5 (kW)

Operating Costs (Re-Design)

The following table is derived from TRACE 700's Energy Cost Budget summary.

Table 22- Energy Cost Budget (Re-Design)

TRACE 700's Energy Cost Budget Output for the Re-Design			
Service	**Utility**	**Energy (10^6 BTU/h)**	**Peak (kBtuh)**
Lights	Electricity	1,766.3	286
Space Heating	Electricity	0.0	0.0
	Gas	2045.2	1,387
	Purchased Steam	0.0	0.0
Space Cooling	Electricity	2093.2	284
	Purchased CHW	0.0	0.0
Pumps	Electricity	201.5	23
Heat Rejection	Electricity	68.7	10
Fans	Electricity	2,241.9	303
Receptacles	Electricity	5510.2	1,012
Total Building Consumption		**13,110.8**	

The following table is derived from TRACE 700's Energy Cost Budget summary.

Table 23- Yearly Operating Cost (Re-Design)

TRACE 700's Energy Cost Budget Output for the Re-Design		
Utility	**Energy (10^6 BTU/h)**	**$/year**
Electricity	11,881.8	$292,433
Gas	2,045.2	$10,226
Purchased Chilled Water	0.0	0.0
Purchased Steam	0.0	0.0
Total	**13,927**	**$302,659**

Emissions Estimate (Re-Design)

The production of electricity yields emissions that are often harmful to the environment. In determining the total annual emissions due to the electricity consumption of the Laboratory, the total electrical energy demanded by the laboratory was multiplied by the lbm of pollutants per kWh. The largest pollutant created will be CO2 and its equivalent.

Table 24-Estimated Emissions per Year (Re-Design)

Emissions Estimate		
Pollutant	**Eastern Emission Factors [lbm/kWh]**	**Per Salk Hall Re-Design[lbm]**
CO_{2e}	1.74	7.18E+06
CO_2	1.64	6.77E+06
CH_4	3.59E-03	1.48E+04
N_2O	3.87E-03	1.60E+04
NO_X	3.00E-03	1.24E+04
SO_X	8.57E-03	3.54E+04
CO	8.54E-04	3.52E+03
TNMOC	7.26E-05	3.00E+02
Lead	1.39E-07	5.74E-01
Mercury	3.66E-08	1.51E-01
PM10	9.26E-05	3.82E+02
Solid Waste	2.05E-01	8.46E+05

The re-design is estimated to produce **14,876,242** pounds of pollutants per year.

The Salk Hall Addition has not yet been constructed and therefore no field data is available for comparison to the estimate.

HVAC System Comparison and Analysis

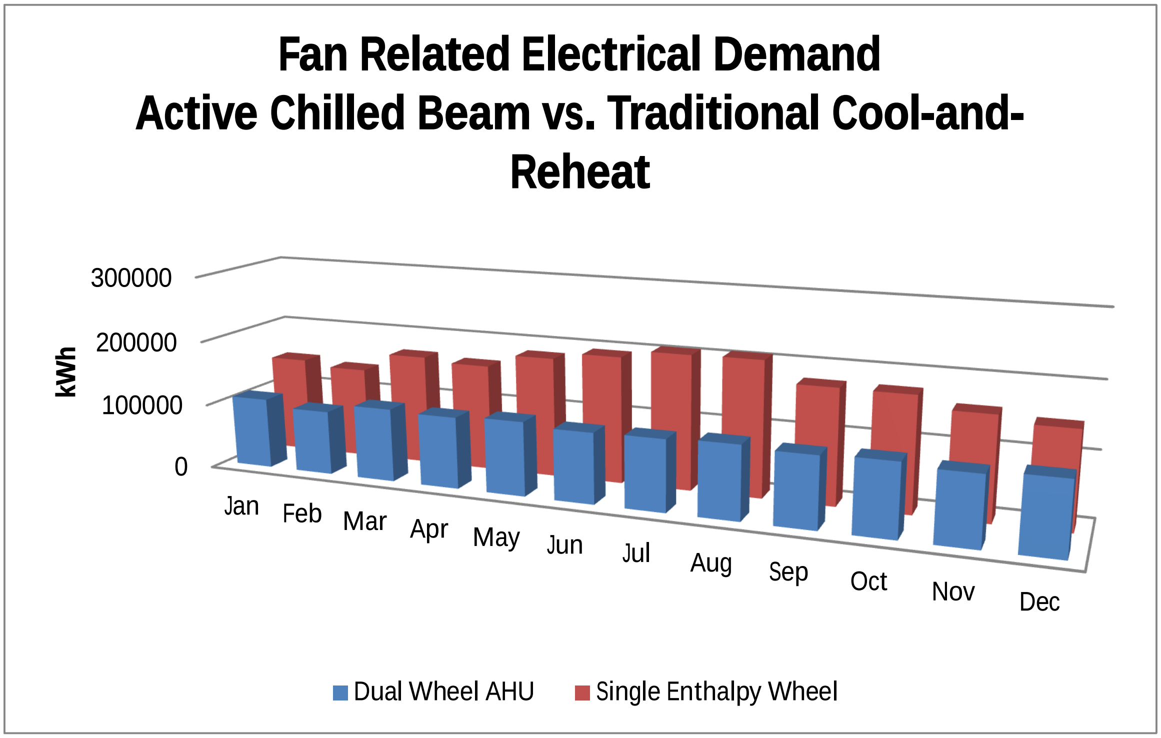
Upon reviewing the TRACE 700 outputs, it immediately becomes clear that the dual-wheel chilled beam system is the more energy efficient design. At its most fundamental level, rating the performance of an HVAC system is most simply exemplified in its annual operating cost. The BOD was estimated to have an annual operating cost of $520,762. The more efficient design, utilizing multiple heat recovery applications, was estimated to have an operating cost of $302,659. When comparing the two designs, the chilled beam yields a **$218,103 savings per year**. The future of HVAC systems lies with being able to minimize their carbon footprint. The traditional cool-and-reheat system is estimated to produce nearly 16 million pounds of pollutants annually. The active chilled beam system is estimated to produce around 10 million pounds of pollutants. The re-design would reduce Salk Hall's carbon foot print by 37.5%.

Figure 17-Sustainable Design Process

1

The re-design's largest load reduction was due to the implementation of Aircuity's "Smart Lab" Demand Control Ventilation sensor package. Safely lowering the required air change rate from 8 ACH to 4ACH in the laboratories drastically reduces Salk Hall's energy consumption. It is important to keep in mind that the air change rate can fluctuate above the 4 ACH minimum at any time if there is a need to improve the indoor environmental quality. The implementation of the demand control ventilation system reduced the electrical load on the fans by 61% when compared to the demand rate of the BOD. The re-design has an ideal, flattened load profile with respect to the airside electrical demand.

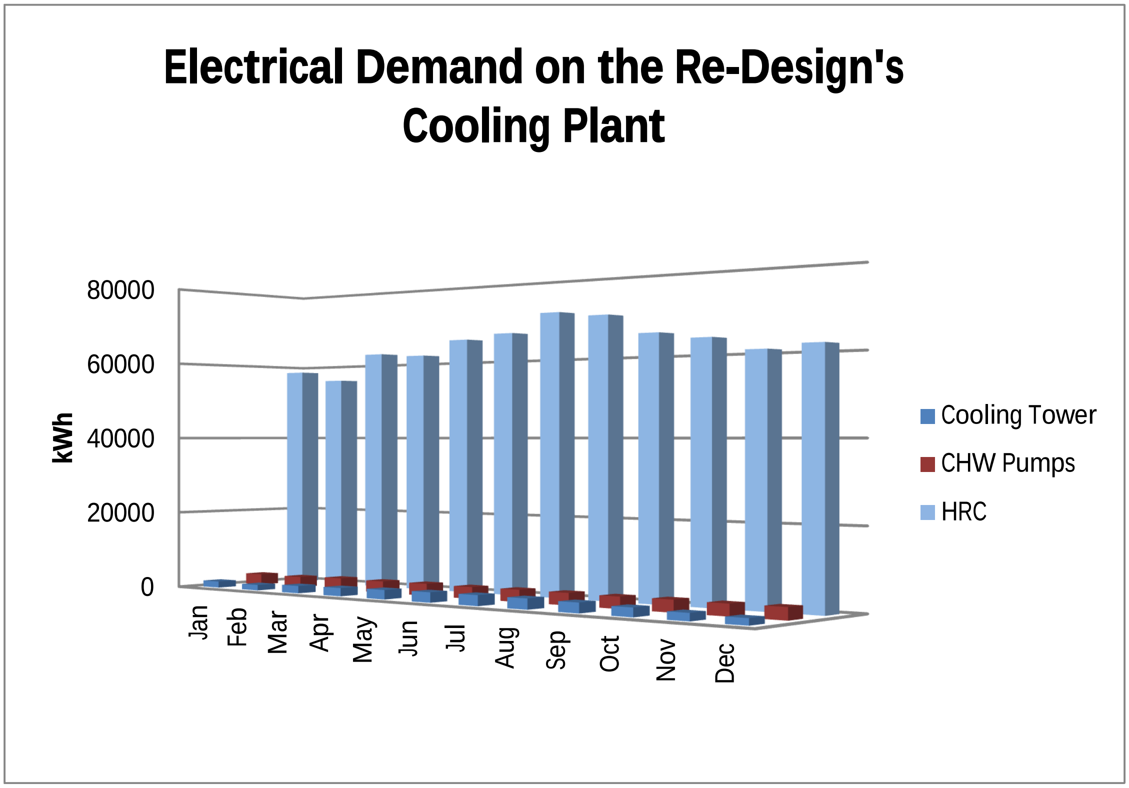
Figure 18-Fan Electrical Demand Comparison



The dedicated heat recovery chiller rejects condenser heat at a water temperature of 110°F into the heating loop. This recovered energy pre-heats hot water in order to meet the domestic hot water load. The Salk Hall BOD's hot water system requires a capacity of 8,760 Therms in order to meet the hot water application loads. By recovering condenser heat in the cooling plant and utilizing it for pre-heat applications, the re-design's hot water system only has to meet a domestic hot water load of 8.8 Therms. This is a 99% reduction in required capacity.

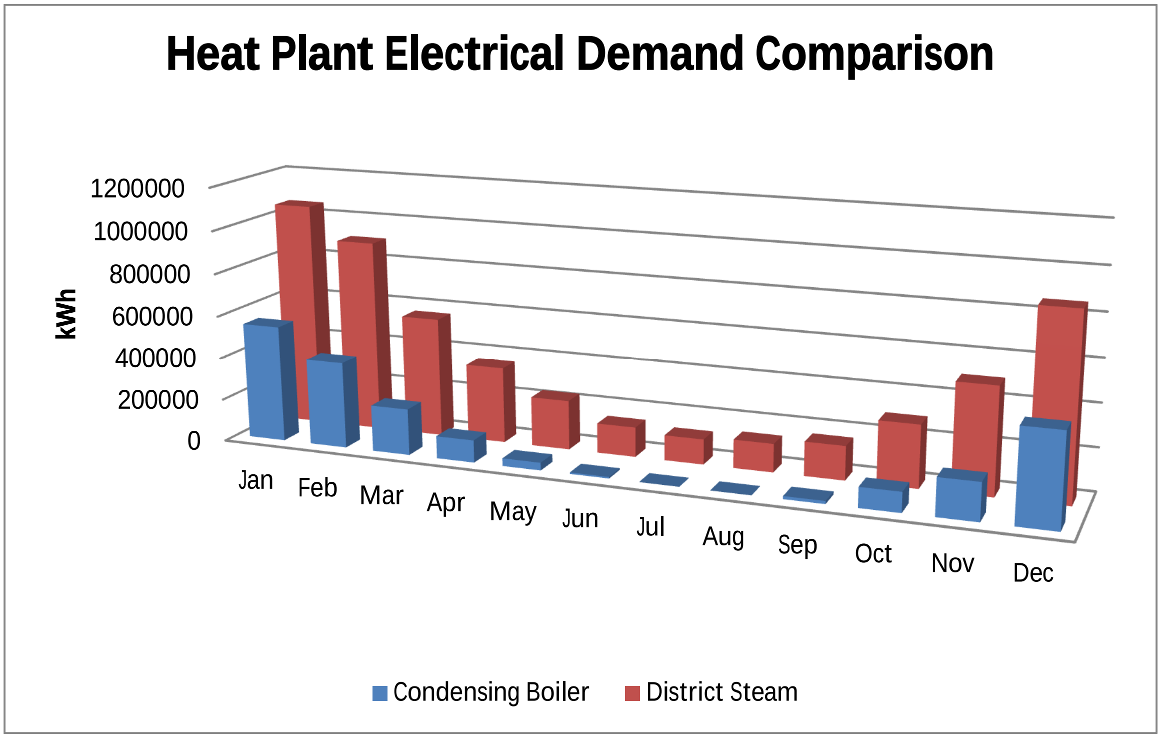
The BOD will require 2,353,112 kWh from the University of Pittsburgh's Campus Chilled Water plant to meet the design cooling load. The Re-Design only requires a 604,556 kWh on the heat recovery chiller. The load differential on the chilled water system between the two design cases is not only a function of the amount of airflow being cooled, but also a lack of any heat recovery from the cooling plant. The load reduction at the cooling tower can also be attributed to the integration of the heat recovery chiller. The double-bundle package successfully bypassed flow around the cooling tower and instead increased its own thermal efficiency by utilizing its internal tower condenser to limit the amount of heat rejected to the outdoors. The re-designed HVAC system experiences a cooling tower load that is 76% less than that of the BOD.

Figure 19-Re-Design's CHW Electrical Profile



While the efficiencies of the condensing boiler and campus steam plant may rival each other, the re-design's ability to operate at lower hot water temperatures, as well as eliminate reheat applications, greatly reduces the demand on the system in comparison to the demand on the campus utility.

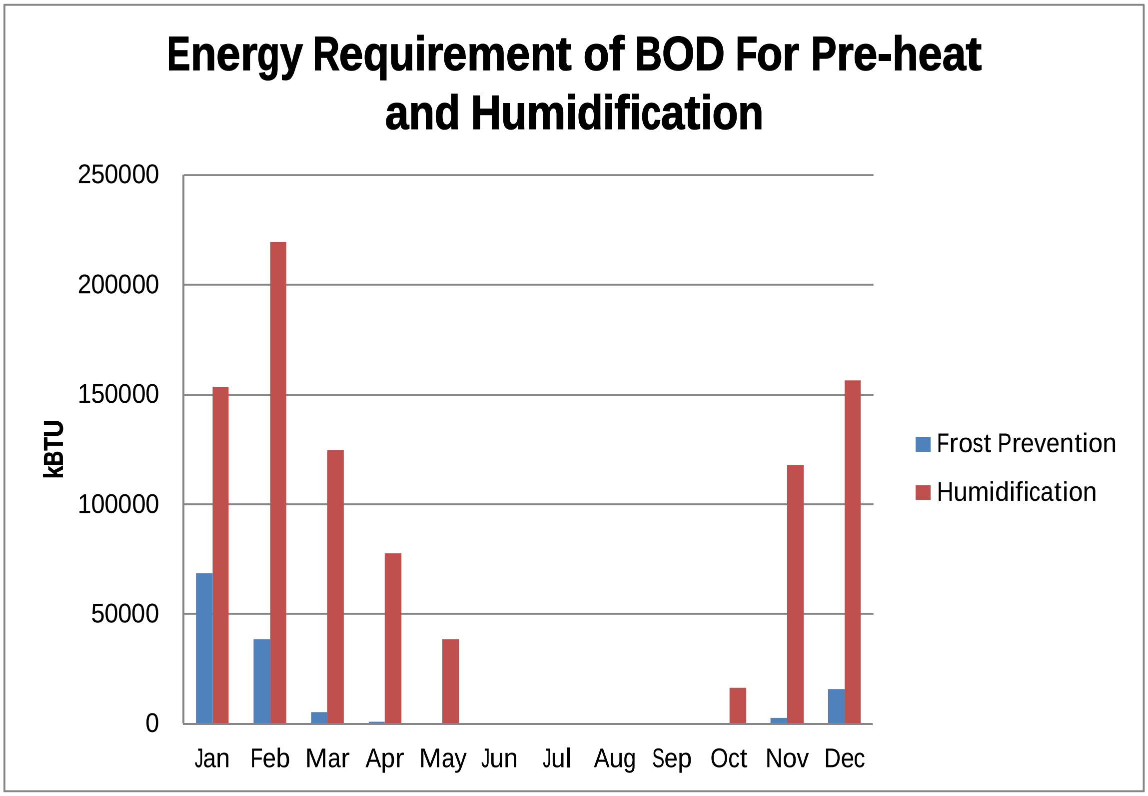
Figure 20-Heating Plant Demand Comparison



The annual electrical demand on the re-design's hot water systems is 61% less than that of the BOD's.

The Pinnacle PVS air handling units will not utilize a pre-heat coil or a humidification system, but will instead manage air conditions as functions of the dual energy wheels. The energy demand profile on the BOD air handling units for frost prevention and humidification is illustrated in Figure 21.

Figure 21-BOD Humidification and Frost Prevention Requirements

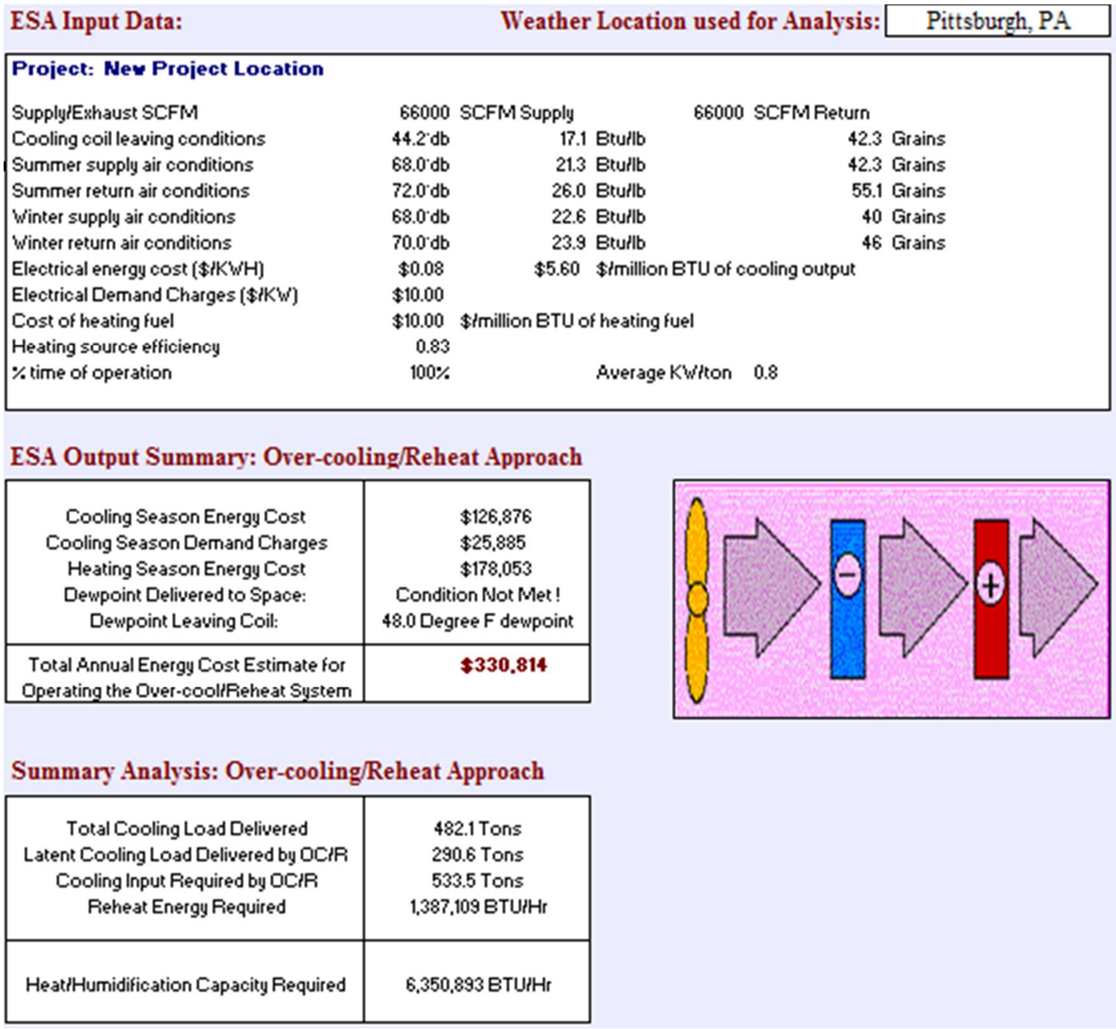


The Pinnacle PVS air handling units would reduce the energy demand on the Salk Hall Addition’s HVAC system by nearly 1,041,000 kBTU per year.

Final Comments on HVAC Re-Design

In order to evaluate the accuracy of the simulated results, a second energy model was created following a typical BIN method in Microsoft Excel. The following figure outlines results of the traditional cool-and-reheat method.

Figure 22-BIN Model for Cool-and-Reheat System



ESA Input Data: **Weather Location used for Analysis:** Pittsburgh, PA

Project: New Project Location

Supply/Exhaust SCFM	66000	SCFM Supply	66000 SCFM Return
Cooling coil leaving conditions	44.2°db	17.1 Btu/lb	42.3 Grains
Summer supply air conditions	68.0°db	21.3 Btu/lb	42.3 Grains
Summer return air conditions	72.0°db	26.0 Btu/lb	55.1 Grains
Winter supply air conditions	68.0°db	22.6 Btu/lb	40 Grains
Winter return air conditions	70.0°db	23.9 Btu/lb	46 Grains
Electrical energy cost ($/KWH)	$0.08	$5.60 $/million BTU of cooling output	
Electrical Demand Charges ($/KW)	$10.00		
Cost of heating fuel	$10.00	$/million BTU of heating fuel	
Heating source efficiency	0.83		
% time of operation	100%	Average KW/ton 0.8	

ESA Output Summary: Over-cooling/Reheat Approach

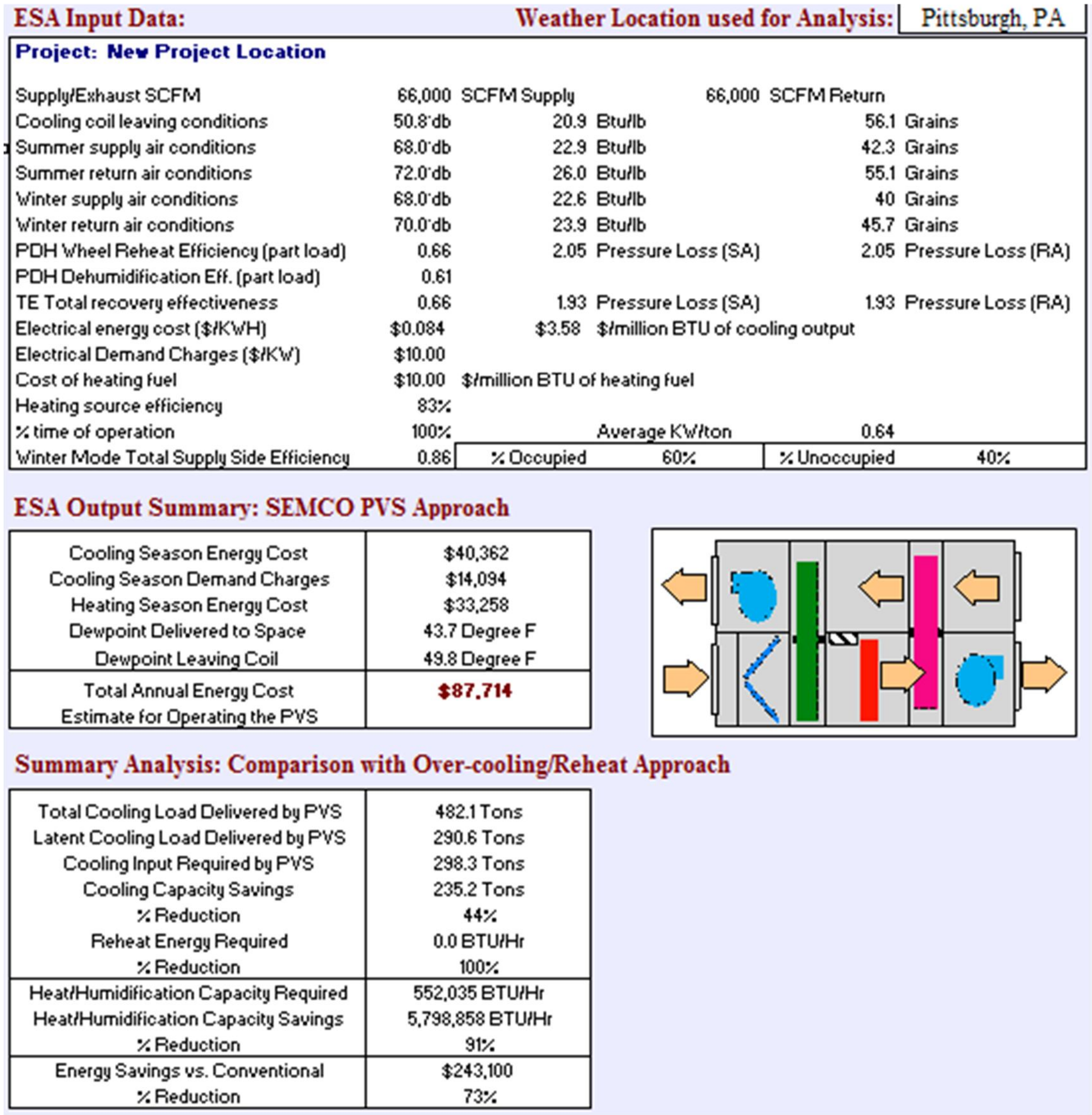
Cooling Season Energy Cost	$126,876
Cooling Season Demand Charges	$25,885
Heating Season Energy Cost	$178,053
Dewpoint Delivered to Space:	Condition Not Met !
Dewpoint Leaving Coil:	48.0 Degree F dewpoint
Total Annual Energy Cost Estimate for Operating the Over-cool/Reheat System	**$330,814**

Summary Analysis: Over-cooling/Reheat Approach

Total Cooling Load Delivered	482.1 Tons
Latent Cooling Load Delivered by OC/R	290.6 Tons
Cooling Input Required by OC/R	533.5 Tons
Reheat Energy Required	1,387,109 BTU/Hr
Heat/Humidification Capacity Required	6,350,893 BTU/Hr

The following figure details the BIN model results of the PVS simulation.

Figure 23-PVS Bin Model



ESA Input Data: **Weather Location used for Analysis:** Pittsburgh, PA

Project: New Project Location

Supply/Exhaust SCFM	66,000	SCFM Supply	66,000 SCFM Return
Cooling coil leaving conditions	50.8°db	20.9 Btu/lb	56.1 Grains
Summer supply air conditions	68.0°db	22.9 Btu/lb	42.3 Grains
Summer return air conditions	72.0°db	26.0 Btu/lb	55.1 Grains
Winter supply air conditions	68.0°db	22.6 Btu/lb	40 Grains
Winter return air conditions	70.0°db	23.9 Btu/lb	45.7 Grains
PDH Wheel Reheat Efficiency (part load)	0.66	2.05 Pressure Loss (SA)	2.05 Pressure Loss (RA)
PDH Dehumidification Eff. (part load)	0.61		
TE Total recovery effectiveness	0.66	1.93 Pressure Loss (SA)	1.93 Pressure Loss (RA)
Electrical energy cost ($/KWH)	$0.084	$3.58 $/million BTU of cooling output	
Electrical Demand Charges ($/KW)	$10.00		
Cost of heating fuel	$10.00	$/million BTU of heating fuel	
Heating source efficiency	83%		
% time of operation	100%	Average KW/ton	0.64
Winter Mode Total Supply Side Efficiency	0.86	% Occupied 60%	% Unoccupied 40%

ESA Output Summary: SEMCO PVS Approach

Cooling Season Energy Cost Cooling Season Demand Charges Heating Season Energy Cost Dewpoint Delivered to Space Dewpoint Leaving Coil	$40,362 $14,094 $33,258 43.7 Degree F 49.8 Degree F
Total Annual Energy Cost Estimate for Operating the PVS	**$87,714**

Summary Analysis: Comparison with Over-cooling/Reheat Approach

Total Cooling Load Delivered by PVS Latent Cooling Load Delivered by PVS Cooling Input Required by PVS Cooling Capacity Savings % Reduction Reheat Energy Required % Reduction	482.1 Tons 290.6 Tons 298.3 Tons 235.2 Tons 44% 0.0 BTU/Hr 100%
Heat/Humidification Capacity Required Heat/Humidification Capacity Savings % Reduction	552,035 BTU/Hr 5,798,858 BTU/Hr 91%
Energy Savings vs. Conventional % Reduction	$243,100 73%

Even though TRACE 700 could not model the re-designed HVAC system exactly the way it operates, the TRACE 700 estimated annual savings are within 11% of the estimated savings predicted by the BIN model. TRACE 700's outputs are an acceptable model for the re-designed HVAC system's performance.

Electrical Breadth

The implementation of a new HVAC system will require a revision in the emergency power service. In order to meet industry design standards and local code requirements, the emergency generator on the first floor of the Salk Hall Addition will be resized accordingly.

Design Considerations

The BOD's emergency power service was designed to operate on a 500kW emergency generator. In order to establish an appropriate design program for the new generator, the University of Pittsburgh's electrical standards were consulted. Division K.22 outlines the requirements and standards for automatic transfer equipment. The following table outlines the emergency power design criteria.

Table 25-Emergency Power Design Considerations

Emergency System Design Consideration					
Voltage Rating	208Y/120 480Y/277	**Phase**	3	**Wires**	4
Automatic Transfer Switch Required	Yes	**# Poles**	4	**Optional ATS Required**	Yes
Alarms	Signals should be sent to the Campus-wide Building Management System to indicate the ATS is in the emergency position				
Monitoring Devices	If elevators or other large motors are connected to the generator, the ATS supplying them will include an in-phase monitor to minimize the voltage transients and system stresses to avoid tripping.				
Emergency Power Loads					
Fire Alarm System	Building Management Panels	Security Panels	Elevators	HVAC Equipment	Tele-data UPS

Power will originate from the University of Pittsburgh Central Utilities Plant at 4,160V. The medium-voltage feeders will terminate in two substations in the new Salk Hall Basement. The building will be provided with two basement substations. One substation will serve all 480V loads within the building, and the other will serve all 208V loads within the building.

Design Strategy

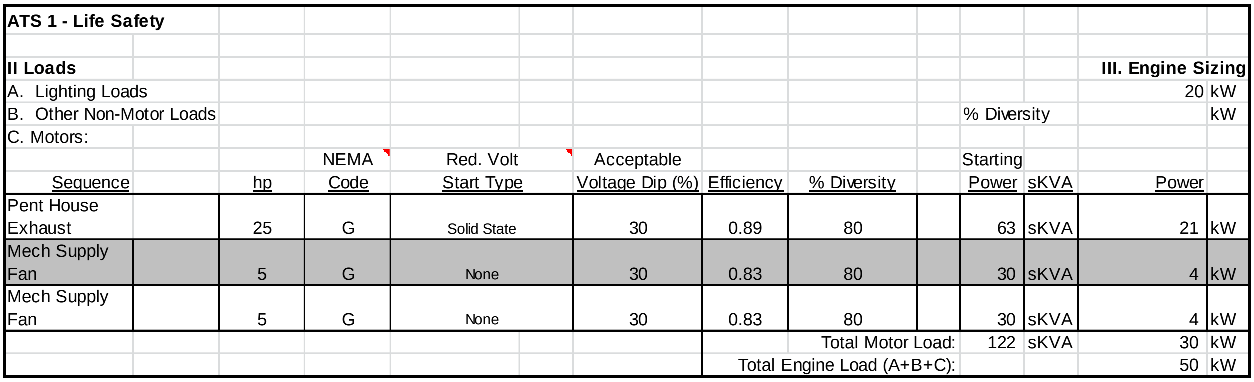
The generator will be located at grade level in an isolated room with sound attenuation on the cooling air intakes and discharges. The generator will have a muffler for the exhaust. The generator will receive its fuel supply directly from the mechanical systems fuel storage and fuel delivery system design. The Automatic Transfer Switches are located on the Ground Floor, separate from the generator room and main electrical room. The ATS switches will be configured with maintenance bypass switches so as to permit continual power to critical loads while being serviced. Separate ATS units will be provided for emergency, legally required standby and optional loads. The following tables detail the procedure that was used to resize the generator.

Table 26-Emergency HVAC Loads

Emergency HVAC Loads					
Service	**HP**	**Service**	**HP**	**Service**	**HP**
AHU-1	40	EF-1	50	HR Wheels-1	1.5
AHU-2	40	EF-2	50	HR Wheels-2	1.5
Total Chilled Water Service	5	Total Hot Water Service	36	Mech. Room Conditioning	35 HP

The following figure outlines the load on the primary automatic transfer switch. Only equipment that is needed to support the emergency power generation equipment is on this switch.

Figure 24-Main Automatic Transfer Switch Schedule



ATS 1 - Life Safety											
II Loads										**III. Engine Sizing**	
A. Lighting Loads										20	kW
B. Other Non-Motor Loads								% Diversity			kW
C. Motors:											
Sequence	hp	NEMA Code	Red. Volt Start Type	Acceptable Voltage Dip (%)	Efficiency	% Diversity		Starting Power	sKVA	Power	
Pent House Exhaust	25	G	Solid State	30	0.89	80		63	sKVA	21	kW
Mech Supply Fan	5	G	None	30	0.83	80		30	sKVA	4	kW
Mech Supply Fan	5	G	None	30	0.83	80		30	sKVA	4	kW
							Total Motor Load:	122	sKVA	30	kW
							Total Engine Load (A+B+C):			50	kW

The following figure is an example of a secondary automatic transfer switch. ATS-2 will be the transfer switch that is responsible for the re-designed HVAC equipment.

Figure 25-ATS 2 Summary

ATS 2										
II Loads									**III. Engine Sizing**	
A. Lighting Loads									0	kW
B. Other Non-Motor Loads							100 % Diversity		190	kW
C. Motors:										
		NEMA	Red. Volt	Acceptable			Starting			
Sequence	hp	Code	Start Type	Voltage Dip (%)	Efficiency	% Diversity	Power	sKVA	Power	
AHU-1	40		None	30	0.90	100	240	sKVA	33	kW
AHU-2	40		None	30	0.90	100	240	sKVA	33	kW
ERW-1	1.5		None	30	0.83	100	9	sKVA	1	kW
ERW-2	1.5		None	30	0.83	100	9	sKVA	1	kW
EF-1a	50		None	30	0.90	100	300	sKVA	41	kW
EF-1b	50		None	30	0.90	100	300	sKVA	41	kW
CHW Pumps	5		None	30	0.83	100	30	sKVA	4	kW
HW Pumps	36		None	30	0.90	100	216	sKVA	30	kW
						Total Motor Load:	1,344	sKVA	186	kW
						Total Engine Load (A+B+C):			376	kW

Figure 26 details the design summary for the emergency generator in which the loads from the automatic transfer switches are summed and further evaluated.

Figure 26-Emergency Generator Design Summary

DESIGN SUMMARY								
	Total	Acceptable	Starting		Total		Power	
Sequence	hp	Voltage Dip (%)	Power		Power		(w/ diversity)	
ATS 1 - Life Safety	35	30	142	sKVA	50	kW	44	kW
ATS 2	224	30	1,534	sKVA	376	kW	376	kW
			Total Engine Load:		426	kW	420	kW
		Maximum Starting Power Required:	**1,534**	**sKVA**				
		Running kW Required:	**420**	**kW**				
		Running kVA @0.8 pf	**525**	**kVA**				
		Running kVA @0.9 pf	**466**	**kVA**				

A new emergency generator will not need to be purchased since the required power generation is only 420 kW. This is under the design capacity of the BOD emergency generator.

Architectural Breadth

The re-design will include a rainwater harvesting system that will provide non-potable water to the domestic water system.

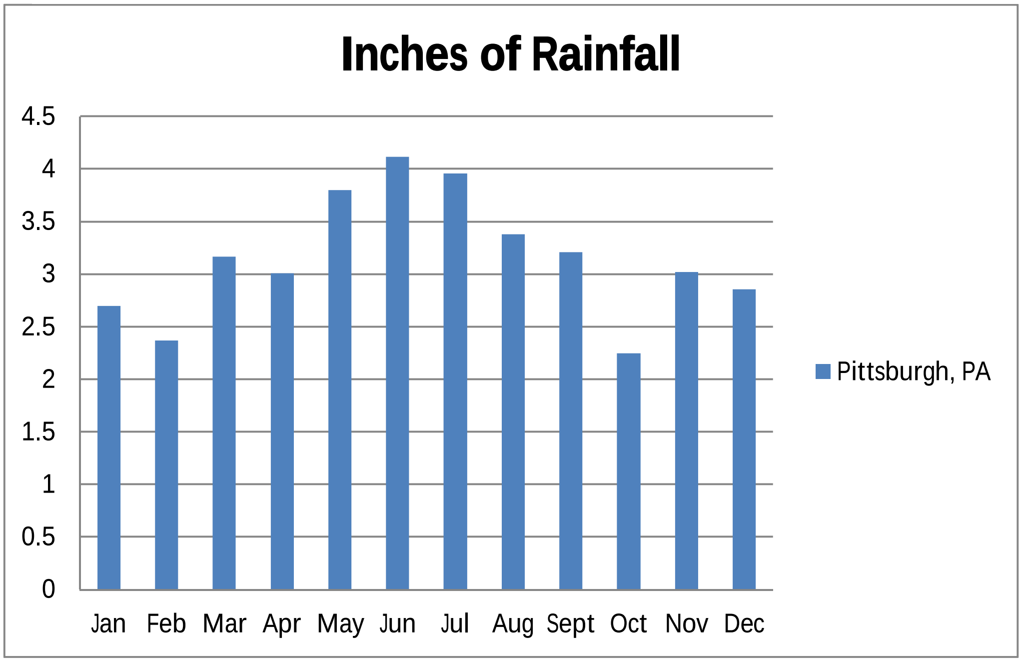
BOD Storm Water Removal Design Strategy

The storm drainage system will convey storm water by gravity from roof and area drains to the municipal storm sewer system. A secondary roof drainage system was provided in order to handle emergency drainage requirements. Area drains at the ground level drain to a collection sump, which is also provided for the foundation drainage. Leaders, roof drains, horizontal storm drainage branches, and headers were sized based according to the Allegheny County Health Department's Rules and Regulations for Plumbing and Building Drainage. The building storm drainage header will connect to the building storm sewer.

Re-design Storm Water Removal Strategy

To conserve water and help reduce the water loads on utility companies, a rainwater analysis was performed on the City of Pittsburgh. The following figure shows the monthly rainfall in Pittsburgh with the annual amount of rainfall totaling 37.8 inches per year.

Figure 27-Monthly Rainfall Analysis



The roof is the only area available at the Salk Hall Addition that could support a rainwater harvesting system. The amount of open roof space that could be used to collect rainwater is nearly 6,600 square feet. Only 800 square feet will be utilized due to the estimated demand for non-potable water.

The following table outlines the design rainwater collection values.

Table 27-Rainwater Harvesting

Rainwater Collection Summary			
Month	**Rainfall Per Month [inches.]**	**Volume (cubic feet)**	**Gallons of Rainwater**
Jan	2.7	180	1346
Feb	2.37	158	1181
Mar	3.17	211	1578
April	3.01	200	1496
May	3.8	253	1892
June	4.12	274	2049.52
July	3.96	264	1974.72
Aug	3.38	255	1907.72
Sep	3.21	213	1596.24
Oct	2.25	150	1122
Nov	3.02	200	1496
Dec	2.86	190	1421.2
Total	**37.85**	**2548**	**37,908**

The rainwater will be stored in Xerxes fiberglass water collection tanks, which can often help to earn LEED points. If the roof is acting as a collection device, one storage tank will be necessary; one 50,000 gallon tank. A 50,000-gallon storage tank has a 12-foot diameter and 68.1 feet length, which requires 7701.93 ft3 of space. If the entire roof area was to be used to collect the rainwater, it would take a little over three tanks occupying 19, 139.41 cubic feet of spacing underground. This is not feasible for the Salk Hall Addition.

The water will be stored in the Xerxes fiberglass water collection tank and pumped into the buildings domestic water lines when the tank is filled. This will allow the building to store the water during most of the winter months for use during the spring and potentially summer. This water will be used for non-potable applications but could potentially be used as potable water if a UV disinfectant system is implemented. The water also has potential to be used for drinking;

however, the tank will need to abide by the NFS Joint Committee for Drinking Water Treatment, which would need further research.

A representative from the Xerxes Tank Company quoted the tank, freight and pipe risers costing approximately $1.15/gallon storage, totaling **$43,700.** The savings in water, at $2.77/kgal, will result in an annual savings of **$105/year.**

References

Active Chilled Beams

Barnet, Barry M. "Chilled Beams For Labs: Using Dual Wheel Energy Recovery." *ASHRAE Journal* (2008): 28-37. Print.

Rumsey, Peter. "Chilled Beams in Labs: Eliminating Reheat & Saving Energy on a Budget." *ASHRAE Journal* 49 (2006): 18-25. Print.

Heat Recovery Chillers & Condensing Boilers

Durkin, Thomas H. "Dedicated Heat Recovery." *ASHRAE Journal* (2003): 18-23. Print.

Rishel, James B. "Reducing Energy Costs With Condensing Boilers and Heat Recovery Chillers." *ASHRAE Journal* (2007): 46-55. Print.

Demand Controlled Ventilation

Sharp, Gordon P. "Demand-Based Control of Lab Air Change Rates." *ASHRAE Journal* (2010): 30-41. Print.

Manufacturer’s product guides were also a key source of information (TROX, SEMCO, AERCO, Phoenix Controls, York, Envirotec)

Appendix A

Required Ventilation Rates

The following table is an example of the Ventilation Rate Procedure outlined by ASHRAE Standard 62.1.

AHU-1 THRU 3	LABORATORY SYSTEM																			
	MINIMUM VENTILATION RATES (COOLING)	ASHRAE Standard 62.1-2007 (Required by LEED NC v2.2 EQp1)								IMC 2006										
Rm No.	Rm Name	Area (Az)	P	Pz	Rp	Ra	Vbz	Ez	Voz	P	Rp	Ra	Voz	Required m Ventilati	Provided nimum C	Difference	4 ACH	6 ACH	10 ACH	Difference (6 ACH & Minimum Provided)
			1000 ft2							1000 ft2										
100	Elevator Lobby	415				0.06	25	1	25			0.05	21	25	250	225				
101	Vestibule	290				0.06	17	1	17			0.05	15	17	250	233				
103	Conference Room	620	50	31	6		186	1	186	*		*	620	620	300	-320				
104	Vending	170	20	3	11		37	1	37					37	150	113				
110	Café Storage	175				0.12	21	1	21					21	125	104				
111	Coffee	300	20	6	11		66	1	66					66	350	284				
112	Corridor	795				0.06	48	1	48			0.05	40	48	1050	1002				
113	Mechanical	1245				0.06	75	1	75					75	100	25				
115	Security	180	5	1	5		5	1	5	*		*	25	25	50	25				
116	MDF	170	5	1	5		4	1	4				24	24	50	26				
122	General Storage	200				0.06	12	1	12					12	150	138				
124	W	150	5	1	5		4	1	4				21	21	250	229				
125	M	150	5	1	5		4	1	4				21	21	250	229				
E-1	Existing 4th Floor Area	630				0.06	38	1	38					38	1050	1012				
200	Elevator Lobby	130				0.06	8	1	8			0.05	7	8	300	292				
204	Tele-Data	175	60	11	6		63	1	63				0	63	375	312				
205	Office	125		3	5	0.06	23	1	23	7	20		18	23	60	38				
206	Office	125		3	5	0.06	23	1	23	7	20		18	23	60	38				
207	Office	125		3	5	0.06	23	1	23	7	20		18	23	60	38				
208	Office	125		3	5	0.06	23	1	23	7	20		18	23	60	38				
209	Office	125		3	5	0.06	23	1	23	7	20		18	23	60	38				
210	Admin	360		1	5	0.06	27	1	27	7	20		50	50	275	225				
212	Office	130		3	5	0.06	23	1	23	7	20		18	23	60	37				
213	Office	130		3	5	0.06	23	1	23	7	20		18	23	60	37				
214	Conference Room	300	50	15	6		90	1	90	50	20		300	300	175	-125				
215	Corridor	350				0.06	21	1	21			0.05	18	21	290	269				
215B	Passage	200				0.06	12	1	12			0.05	10	12	640	628				
217	M. Restroom	150						1		*	*		225	225	250	25				
218	W. Restroom	150						1		*	*	*	225	225	250	25				
221	Break Room	595	25	15	10		149	1	149				0	149	550	401				
222	East Laboratory Control Zone, Lockers, Equipment Alcove, Fume Hood Alcove	3260	25	82	17		1386	1	1386				0	4347	3730	-617	2173	3260	4347	470
222C	GLP Lab	200	25	5	17		85	1	85				0	267	35	-232	120	180	267	-145
222D	Tissue Culture Alcove	95	25	2	17		40	1	40				0	127	35	-92	57	85.5	127	-50.5
222G	Cold Room	80						1					0	0	50	50				
222H	Dark Room	60						1					0	0	35	35				
222J	Virus Lab	100	25	3	17		43	1	43				0	133	35	-98	60	90	133	-55
223	West Laboratory Control Zone, Lockers, Protien Lab	3140	25	79	17		1335	1	1335				0	4187	3940	-247	2093	3140	4187	800
223B	Tissue Culture Alcove	210	25	5	17		89	1	89				0	280	35	-245	126	189	280	-154
223C	Microscopy Alcove	75	25	2	17		32	1	32				0	100	350	250	45	67.5	100	282.5
223F	Enviornmental Room	80						1					0	107	50	-57	48	72	107	-22
223G	Mass Spec Lab	400	25	10	17		170	1	170				0	533	160	-373	240	360	533	-200
224	Equipment Corridor	680				0.06	41	1	41			0.05	34	41	755	714				
224A	Glasswash	145						1					0	0	35	35				
225	Equipment Corridor	800				0.06	48	1	48			0.05	40	48	600	552				
230	Commons	1910	150	287	5	0.06	1547	1	1547				0	1547	2000	453				

Appendix B

Peak Internal Loads

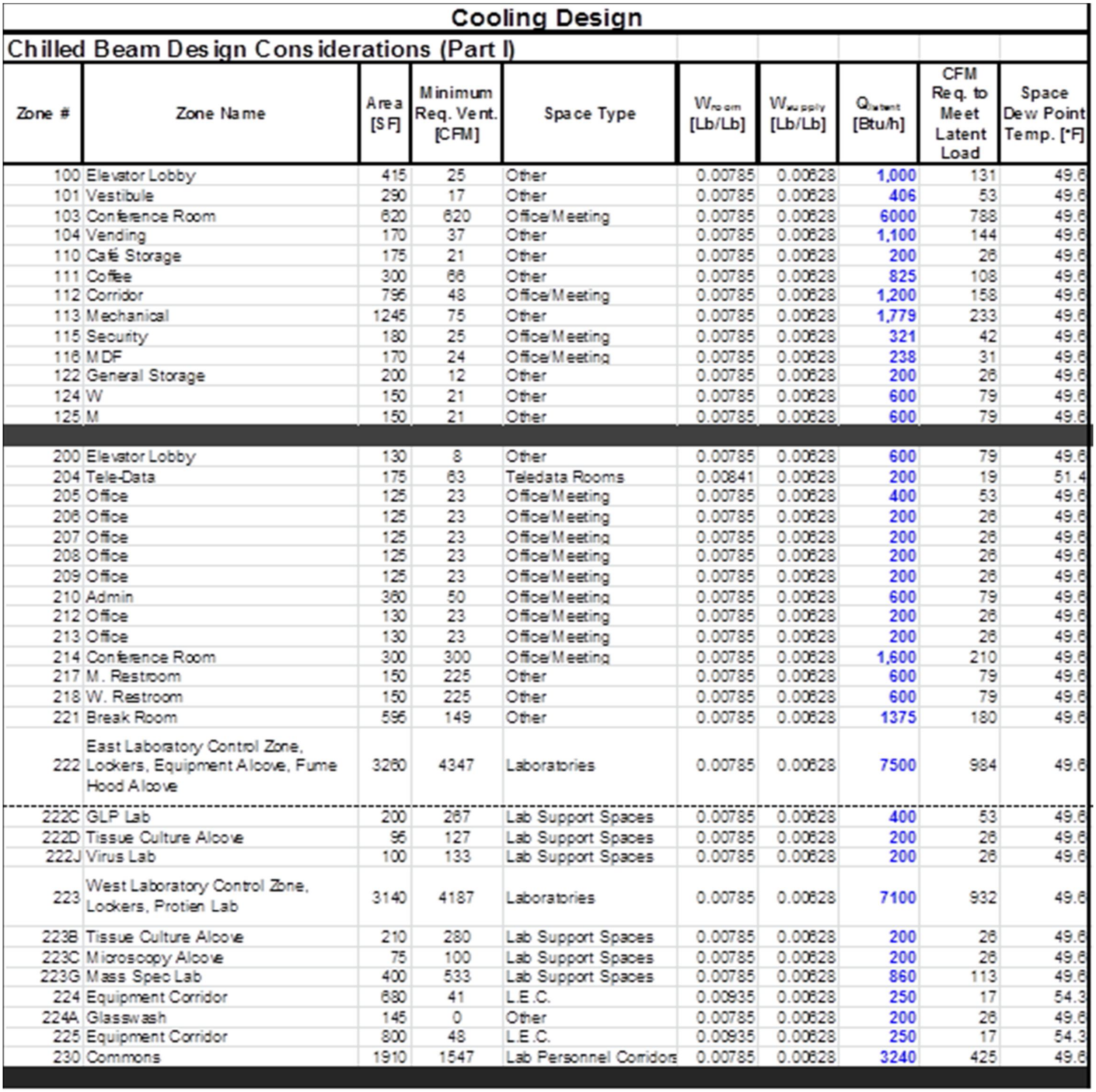
The following table is an example of the peak internal loads, per TRACE 700.

		Lights			People				Misc. Equipment			
System Zone Room		Space Load Btu/h	Ret Air Load Btu/h	CLF	Space Sensible Btu/h	Ret Air Sensible Btu/h	Space Latent Btu/h	CLF	Space Sensible Btu/h	Space Latent Btu/h	Ret Air Load Btu/h	CLF
113 Mechanical	Zn Tot/Ave	4,044	0	0.952	2,052	0	1,779	0.957	16,670	0	0	0.981
115 Security	Zn Tot/Ave	936	0	0.952	299	0	321	0.965	4,084	0	0	0.950
101 Vestibule	Zn Tot/Ave	1,225	0	0.952	472	0	406	0.961	1,885	0	0	0.952
116 MDF	Zn Tot/Ave	718	0	0.952	276	0	238	0.961	1,105	0	0	0.952
100 Elevator Lobby	Zn Tot/Ave	1,558	0	1.000	1,120	0	1,000	0.942	1,310	0	0	0.925
103 Conference Room	Zn Tot/Ave	2,187	0	0.940	6,870	0	6,000	0.953	4,983	0	0	0.942
104 Vending	Zn Tot/Ave	638	0	1.000	1,008	0	1,100	0.958	1,641	0	0	0.943
110 Cafe Storage	Zn Tot/Ave	669	0	0.861	192	0	200	0.872	1,011	0	0	0.846
111 Coffee	Zn Tot/Ave	1,126	0	1.000	756	0	825	0.958	2,897	0	0	0.943
112 Corridor	Zn Tot/Ave	2,985	0	1.000	1,345	0	1,200	0.942	2,521	0	0	0.929
122 General Storage	Zn Tot/Ave	641	0	0.940	231	0	200	0.957	2,665	0	0	0.976
124/125 Rest Rooms	Zn Tot/Ave	1,126	0	1.000	1,385	0	1,200	0.957	962	0	0	0.939
200 Elevator Lobby	Zn Tot/Ave	1,952	0	1.000	2,769	0	2,400	0.957	1,667	0	0	0.939
204 Teledata	Zn Tot/Ave	2,245	0	0.940	923	0	800	0.957	9,327	0	0	0.976
205 Office	Zn Tot/Ave	2,049	0	0.924	1,753	0	1,600	0.931	3,019	0	0	0.885
206 Office	Zn Tot/Ave	2,048	0	0.923	876	0	800	0.931	3,017	0	0	0.884
207 Office	Zn Tot/Ave	2,085	0	0.940	895	0	800	0.942	3,121	0	0	0.914
208 Office	Zn Tot/Ave	2,085	0	0.940	895	0	800	0.942	3,123	0	0	0.915
209 Office	Zn Tot/Ave	2,085	0	0.940	895	0	800	0.942	3,121	0	0	0.914
210 Admninstration	Zn Tot/Ave	5,847	0	0.915	2,601	0	2,400	0.926	8,876	0	0	0.903
212 Office	Zn Tot/Ave	2,168	0	0.940	895	0	800	0.942	3,247	0	0	0.915
213 Office	Zn Tot/Ave	2,182	0	0.946	902	0	800	0.946	3,295	0	0	0.928
214 Conference Room	Zn Tot/Ave	4,288	0	0.962	7,486	0	6,400	0.964	9,767	0	0	0.954
215/217/218 Restrooms&Corridor	Zn Tot/Ave	9,761	0	1.000	5,538	0	4,800	0.957	8,336	0	0	0.939
221 Break Room	Zn Tot/Ave	8,935	0	1.000	4,399	0	5,500	0.900	20,713	0	0	0.850
222(1)-East Lab	Zn Tot/Ave	18,061	0	0.861	16,080	0	16,000	0.891	27,366	0	0	0.835
222(2)-East Lab	Zn Tot/Ave	36,947	0	0.940	9,230	0	10,000	0.962	160,043	0	0	0.930
222(3)-Staff Lockers	Zn Tot/Ave	3,900	0	0.940	923	0	800	0.957	17,067	0	0	0.939
222(4) Fume Hood Alcove	Zn Tot/Ave	2,053	0	0.940	1,846	0	1,600	0.957	8,977	0	0	0.939
222(5) Equipment Above	Zn Tot/Ave	2,053	0	0.940	923	0	800	0.957	8,977	0	0	0.939
222C GLP Lab	Zn Tot/Ave	4,105	0	0.940	1,846	0	1,600	0.957	17,955	0	0	0.939
222D Tissue Culture Above	Zn Tot/Ave	2,053	0	0.940	923	0	800	0.957	8,977	0	0	0.939
222J Virus Lab	Zn Tot/Ave	2,053	0	0.940	923	0	800	0.957	8,977	0	0	0.939
223(1) West Lab	Zn Tot/Ave	37,184	0	0.946	9,370	0	10,000	0.968	161,694	0	0	0.940
223(2) West Lab	Zn Tot/Ave	17,873	0	0.861	16,080	0	16,000	0.891	27,083	0	0	0.835
223(3) Staff Lockers	Zn Tot/Ave	3,412	0	0.940	923	0	800	0.957	17,067	0	0	0.939
223(4) Protien Lab	Zn Tot/Ave	2,053	0	0.940	1,846	0	1,600	0.957	8,977	0	0	0.939
223B Tissue Culture	Zn Tot/Ave	4,269	0	0.940	923	0	800	0.957	18,673	0	0	0.939

Appendix C

Chilled Beam Calculations

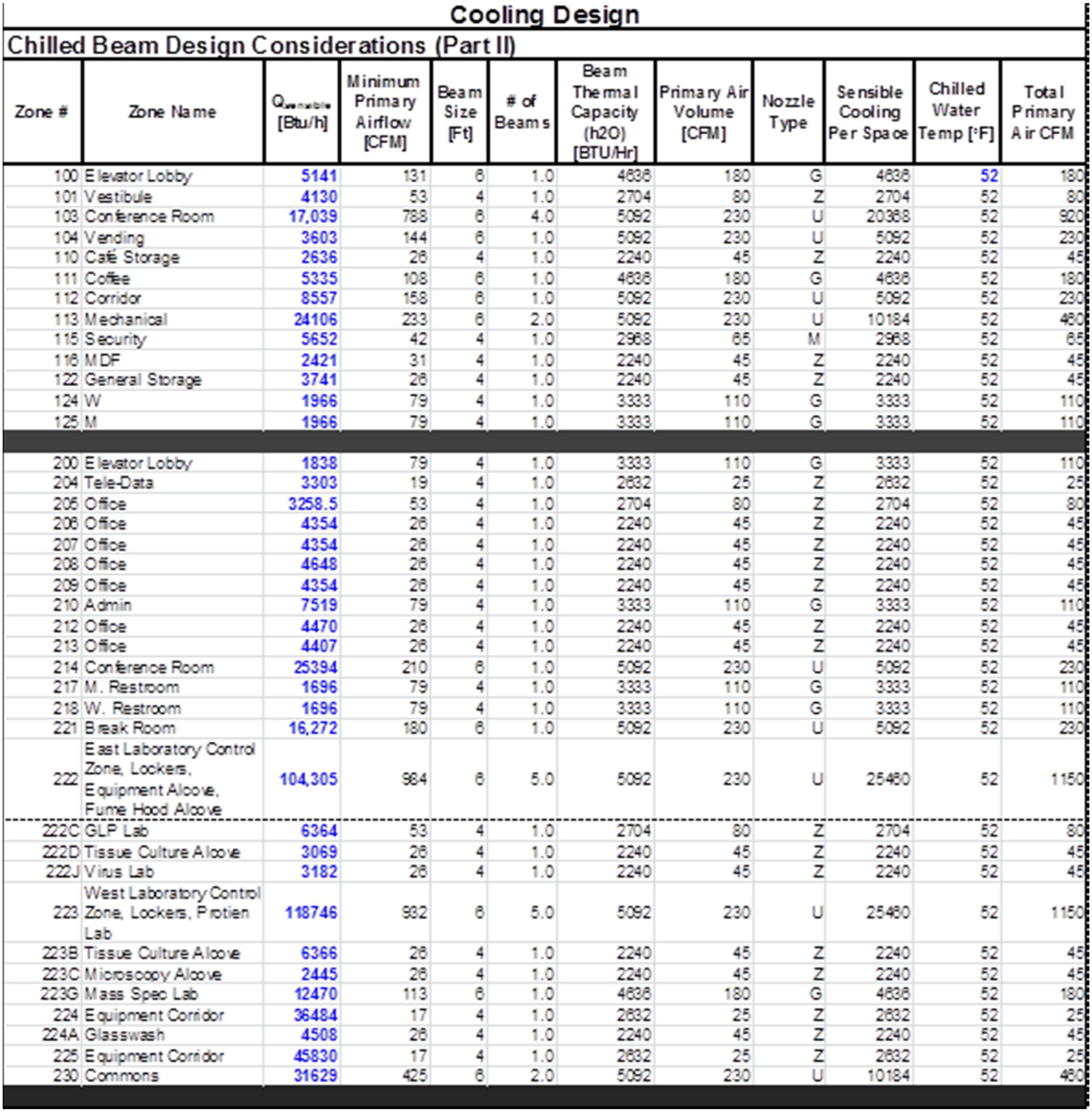
The following table sizes chilled beams based foremost on the amount of airflow required to meet the space latent load, but as well as by the total sensible load within the space.



Cooling Design

Chilled Beam Design Considerations (Part I)

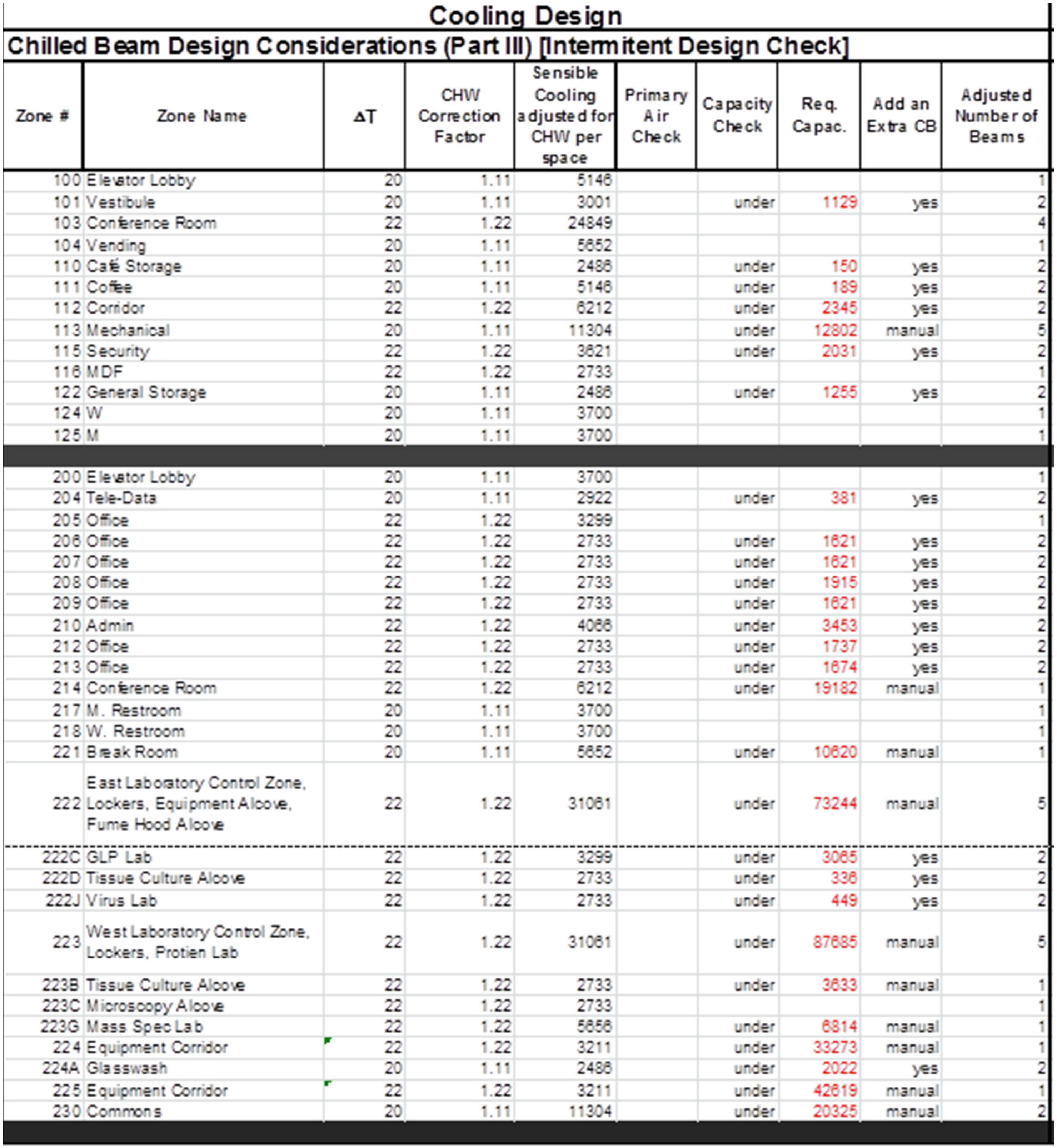
Zone #	Zone Name	Area [SF]	Minimum Req. Vent. [CFM]	Space Type	W_{room} [Lb/Lb]	W_{supply} [Lb/Lb]	Q_{latent} [Btu/h]	CFM Req. to Meet Latent Load	Space Dew Point Temp. [°F]
100	Elevator Lobby	415	25	Other	0.00785	0.00628	1,000	131	49.6
101	Vestibule	290	17	Other	0.00785	0.00628	406	53	49.6
103	Conference Room	620	620	Office/Meeting	0.00785	0.00628	6000	788	49.6
104	Vending	170	37	Other	0.00785	0.00628	1,100	144	49.6
110	Café Storage	175	21	Other	0.00785	0.00628	200	26	49.6
111	Coffee	300	66	Other	0.00785	0.00628	825	108	49.6
112	Corridor	796	48	Office/Meeting	0.00785	0.00628	1,200	158	49.6
113	Mechanical	1245	75	Other	0.00785	0.00628	1,779	233	49.6
115	Security	180	25	Office/Meeting	0.00785	0.00628	321	42	49.6
116	MDF	170	24	Office/Meeting	0.00785	0.00628	238	31	49.6
122	General Storage	200	12	Other	0.00785	0.00628	200	26	49.6
124	W	150	21	Other	0.00785	0.00628	600	79	49.6
125	M	150	21	Other	0.00785	0.00628	600	79	49.6
200	Elevator Lobby	130	8	Other	0.00785	0.00628	600	79	49.6
204	Tele-Data	175	63	Teledata Rooms	0.00841	0.00628	200	19	51.4
205	Office	125	23	Office/Meeting	0.00785	0.00628	400	53	49.6
206	Office	125	23	Office/Meeting	0.00785	0.00628	200	26	49.6
207	Office	125	23	Office/Meeting	0.00785	0.00628	200	26	49.6
208	Office	125	23	Office/Meeting	0.00785	0.00628	200	26	49.6
209	Office	125	23	Office/Meeting	0.00785	0.00628	200	26	49.6
210	Admin	360	50	Office/Meeting	0.00785	0.00628	600	79	49.6
212	Office	130	23	Office/Meeting	0.00785	0.00628	200	26	49.6
213	Office	130	23	Office/Meeting	0.00785	0.00628	200	26	49.6
214	Conference Room	300	300	Office/Meeting	0.00785	0.00628	1,600	210	49.6
217	M. Restroom	150	225	Other	0.00785	0.00628	600	79	49.6
218	W. Restroom	150	225	Other	0.00785	0.00628	600	79	49.6
221	Break Room	596	149	Other	0.00785	0.00628	1375	180	49.6
222	East Laboratory Control Zone, Lockers, Equipment Alcove, Fume Hood Alcove	3260	4347	Laboratories	0.00785	0.00628	7500	984	49.6
222C	GLP Lab	200	267	Lab Support Spaces	0.00785	0.00628	400	53	49.6
222D	Tissue Culture Alcove	96	127	Lab Support Spaces	0.00785	0.00628	200	26	49.6
222J	Virus Lab	100	133	Lab Support Spaces	0.00785	0.00628	200	26	49.6
223	West Laboratory Control Zone, Lockers, Protien Lab	3140	4187	Laboratories	0.00785	0.00628	7100	932	49.6
223B	Tissue Culture Alcove	210	280	Lab Support Spaces	0.00785	0.00628	200	26	49.6
223C	Microscopy Alcove	75	100	Lab Support Spaces	0.00785	0.00628	200	26	49.6
223G	Mass Spec Lab	400	533	Lab Support Spaces	0.00785	0.00628	860	113	49.6
224	Equipment Corridor	680	41	L.E.C.	0.00935	0.00628	250	17	54.3
224A	Glasswash	145	0	Other	0.00785	0.00628	200	26	49.6
225	Equipment Corridor	800	48	L.E.C.	0.00935	0.00628	250	17	54.3
230	Commons	1910	1547	Lab Personnel Corridors	0.00785	0.00628	3240	425	49.6



Cooling Design

Chilled Beam Design Considerations (Part II)

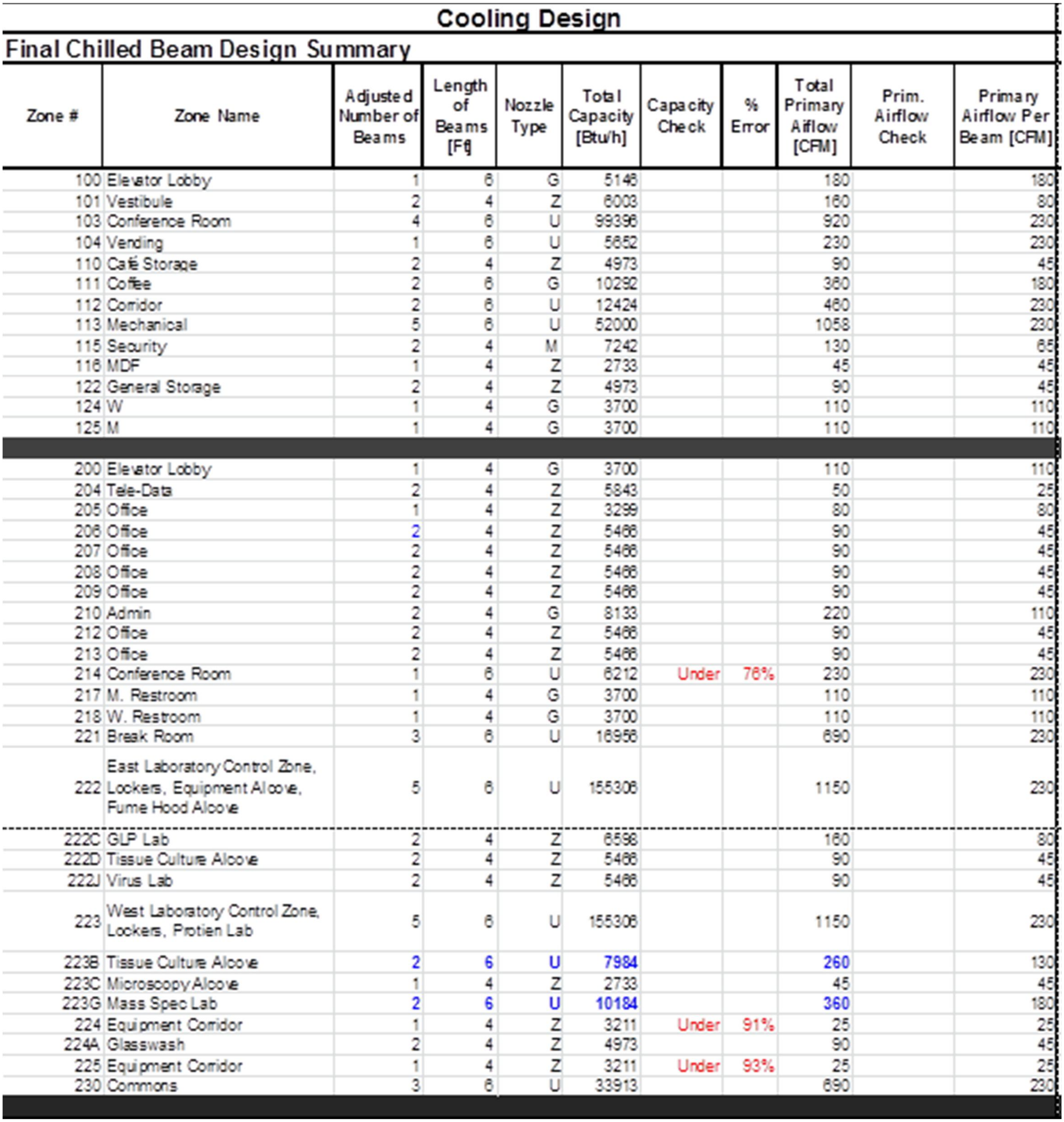
Zone #	Zone Name	$Q_{sensible}$ [Btu/h]	Minimum Primary Airflow [CFM]	Beam Size [Ft]	# of Beams	Beam Thermal Capacity (h2O) [BTU/Hr]	Primary Air Volume [CFM]	Nozzle Type	Sensible Cooling Per Space	Chilled Water Temp [°F]	Total Primary Air CFM
100	Elevator Lobby	5141	131	6	1.0	4636	180	G	4636	52	180
101	Vestibule	4130	53	4	1.0	2704	80	Z	2704	52	80
103	Conference Room	17,039	788	6	4.0	5092	230	U	20368	52	920
104	Vending	3603	144	6	1.0	5092	230	U	5092	52	230
110	Café Storage	2636	26	4	1.0	2240	45	Z	2240	52	45
111	Coffee	5335	108	6	1.0	4636	180	G	4636	52	180
112	Corridor	8557	158	6	1.0	5092	230	U	5092	52	230
113	Mechanical	24106	233	6	2.0	5092	230	U	10184	52	460
115	Security	5652	42	4	1.0	2968	65	M	2968	52	65
116	MDF	2421	31	4	1.0	2240	45	Z	2240	52	45
122	General Storage	3741	26	4	1.0	2240	45	Z	2240	52	45
124	W	1966	79	4	1.0	3333	110	G	3333	52	110
125	M	1966	79	4	1.0	3333	110	G	3333	52	110
200	Elevator Lobby	1838	79	4	1.0	3333	110	G	3333	52	110
204	Tele-Data	3303	19	4	1.0	2632	25	Z	2632	52	25
205	Office	3258.5	53	4	1.0	2704	80	Z	2704	52	80
206	Office	4354	26	4	1.0	2240	45	Z	2240	52	45
207	Office	4354	26	4	1.0	2240	45	Z	2240	52	45
208	Office	4648	26	4	1.0	2240	45	Z	2240	52	45
209	Office	4354	26	4	1.0	2240	45	Z	2240	52	45
210	Admin	7519	79	4	1.0	3333	110	G	3333	52	110
212	Office	4470	26	4	1.0	2240	45	Z	2240	52	45
213	Office	4407	26	4	1.0	2240	45	Z	2240	52	45
214	Conference Room	25394	210	6	1.0	5092	230	U	5092	52	230
217	M. Restroom	1696	79	4	1.0	3333	110	G	3333	52	110
218	W. Restroom	1696	79	4	1.0	3333	110	G	3333	52	110
221	Break Room	16,272	180	6	1.0	5092	230	U	5092	52	230
222	East Laboratory Control Zone, Lockers, Equipment Alcove, Fume Hood Alcove	104,305	984	6	5.0	5092	230	U	25460	52	1150
222C	GLP Lab	6364	53	4	1.0	2704	80	Z	2704	52	80
222D	Tissue Culture Alcove	3069	26	4	1.0	2240	45	Z	2240	52	45
222J	Virus Lab	3182	26	4	1.0	2240	45	Z	2240	52	45
223	West Laboratory Control Zone, Lockers, Protien Lab	118746	932	6	5.0	5092	230	U	25460	52	1150
223B	Tissue Culture Alcove	6366	26	4	1.0	2240	45	Z	2240	52	45
223C	Microscopy Alcove	2445	26	4	1.0	2240	45	Z	2240	52	45
223G	Mass Spec Lab	12470	113	6	1.0	4636	180	G	4636	52	180
224	Equipment Corridor	36484	17	4	1.0	2632	25	Z	2632	52	25
224A	Glasswash	4508	26	4	1.0	2240	45	Z	2240	52	45
225	Equipment Corridor	45830	17	4	1.0	2632	25	Z	2632	52	25
230	Commons	31629	425	6	2.0	5092	230	U	10184	52	460



Cooling Design

Chilled Beam Design Considerations (Part III) [Intermitent Design Check]

Zone #	Zone Name	∆T	CHW Correction Factor	Sensible Cooling adjusted for CHW per space	Primary Air Check	Capacity Check	Req. Capac.	Add an Extra CB	Adjusted Number of Beams
100	Elevator Lobby	20	1.11	5146					1
101	Vestibule	20	1.11	3001		under	1129	yes	2
103	Conference Room	22	1.22	24849					4
104	Vending	20	1.11	5652					1
110	Café Storage	20	1.11	2486		under	150	yes	2
111	Coffee	20	1.11	5146		under	189	yes	2
112	Corridor	22	1.22	6212		under	2345	yes	2
113	Mechanical	20	1.11	11304		under	12802	manual	5
115	Security	22	1.22	3621		under	2031	yes	2
116	MDF	22	1.22	2733					1
122	General Storage	20	1.11	2486		under	1255	yes	2
124	W	20	1.11	3700					1
125	M	20	1.11	3700					1
200	Elevator Lobby	20	1.11	3700					1
204	Tele-Data	20	1.11	2922		under	381	yes	2
205	Office	22	1.22	3299					1
206	Office	22	1.22	2733		under	1621	yes	2
207	Office	22	1.22	2733		under	1621	yes	2
208	Office	22	1.22	2733		under	1915	yes	2
209	Office	22	1.22	2733		under	1621	yes	2
210	Admin	22	1.22	4066		under	3453	yes	2
212	Office	22	1.22	2733		under	1737	yes	2
213	Office	22	1.22	2733		under	1674	yes	2
214	Conference Room	22	1.22	6212		under	19182	manual	1
217	M. Restroom	20	1.11	3700					1
218	W. Restroom	20	1.11	3700					1
221	Break Room	20	1.11	5652		under	10620	manual	1
222	East Laboratory Control Zone, Lockers, Equipment Alcove, Fume Hood Alcove	22	1.22	31061		under	73244	manual	5
222C	GLP Lab	22	1.22	3299		under	3065	yes	2
222D	Tissue Culture Alcove	22	1.22	2733		under	336	yes	2
222J	Virus Lab	22	1.22	2733		under	449	yes	2
223	West Laboratory Control Zone, Lockers, Protien Lab	22	1.22	31061		under	87685	manual	5
223B	Tissue Culture Alcove	22	1.22	2733		under	3633	manual	1
223C	Microscopy Alcove	22	1.22	2733					1
223G	Mass Spec Lab	22	1.22	5656		under	6814	manual	1
224	Equipment Corridor	22	1.22	3211		under	33273	manual	1
224A	Glasswash	20	1.11	2486		under	2022	yes	2
225	Equipment Corridor	22	1.22	3211		under	42619	manual	1
230	Commons	20	1.11	11304		under	20325	manual	2



Cooling Design

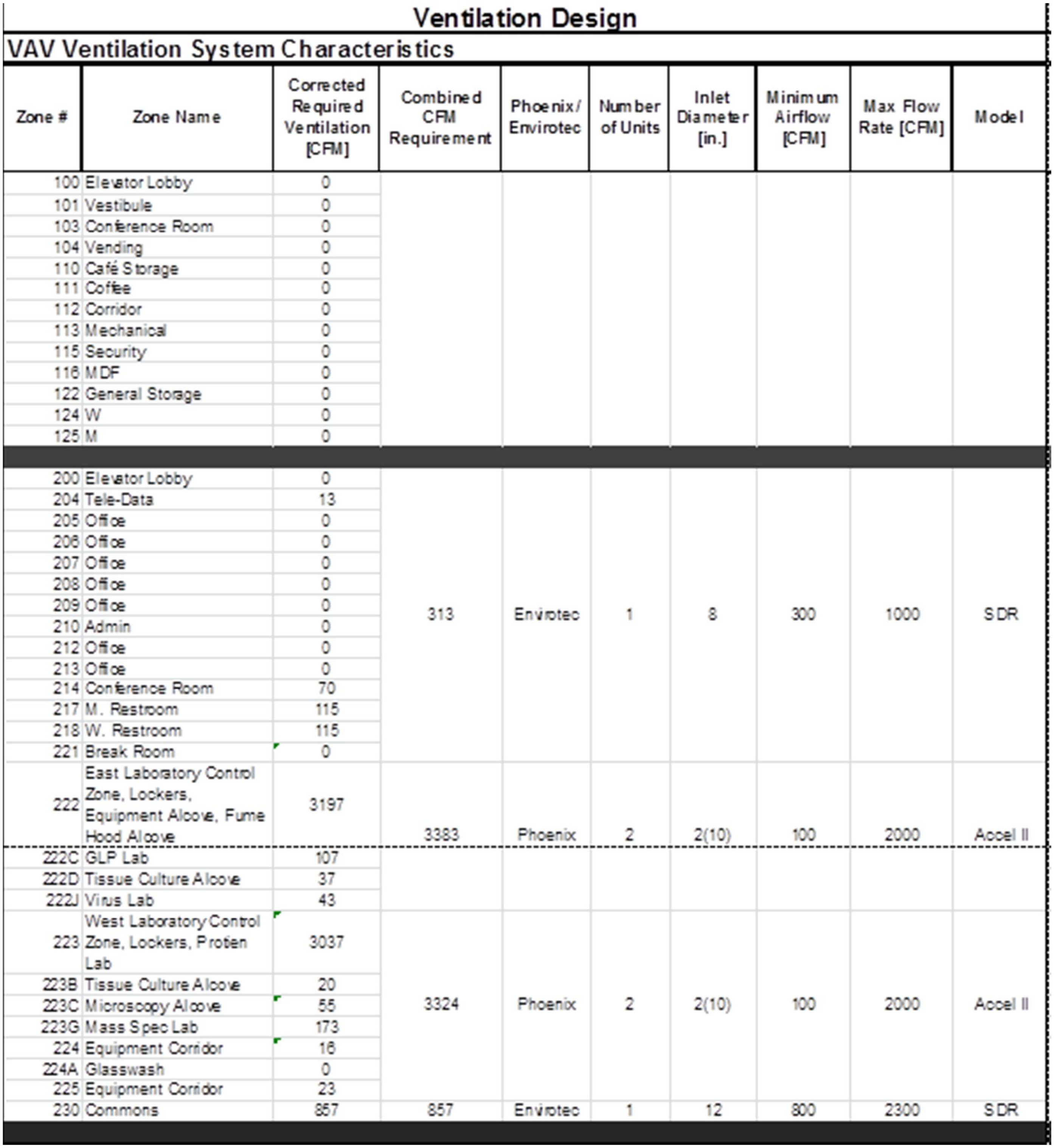
Final Chilled Beam Design Summary

Zone #	Zone Name	Adjusted Number of Beams	Length of Beams [Ft]	Nozzle Type	Total Capacity [Btu/h]	Capacity Check	% Error	Total Primary Aiflow [CFM]	Prim. Airflow Check	Primary Airflow Per Beam [CFM]
100	Elevator Lobby	1	6	G	5146			180		180
101	Vestibule	2	4	Z	6003			160		80
103	Conference Room	4	6	U	99396			920		230
104	Vending	1	6	U	5652			230		230
110	Café Storage	2	4	Z	4973			90		45
111	Coffee	2	6	G	10292			360		180
112	Corridor	2	6	U	12424			460		230
113	Mechanical	5	6	U	52000			1058		230
115	Security	2	4	M	7242			130		65
116	MDF	1	4	Z	2733			45		45
122	General Storage	2	4	Z	4973			90		45
124	W	1	4	G	3700			110		110
125	M	1	4	G	3700			110		110
200	Elevator Lobby	1	4	G	3700			110		110
204	Tele-Data	2	4	Z	5843			50		25
205	Office	1	4	Z	3299			80		80
206	Office	2	4	Z	5466			90		45
207	Office	2	4	Z	5466			90		45
208	Office	2	4	Z	5466			90		45
209	Office	2	4	Z	5466			90		45
210	Admin	2	4	G	8133			220		110
212	Office	2	4	Z	5466			90		45
213	Office	2	4	Z	5466			90		45
214	Conference Room	1	6	U	6212	Under	76%	230		230
217	M. Restroom	1	4	G	3700			110		110
218	W. Restroom	1	4	G	3700			110		110
221	Break Room	3	6	U	16956			690		230
222	East Laboratory Control Zone, Lockers, Equipment Alcove, Fume Hood Alcove	5	6	U	155306			1150		230
222C	GLP Lab	2	4	Z	6598			160		80
222D	Tissue Culture Alcove	2	4	Z	5466			90		45
222J	Virus Lab	2	4	Z	5466			90		45
223	West Laboratory Control Zone, Lockers, Protien Lab	5	6	U	155306			1150		230
223B	Tissue Culture Alcove	2	6	U	7984			260		130
223C	Microscopy Alcove	1	4	Z	2733			45		45
223G	Mass Spec Lab	2	6	U	10184			360		180
224	Equipment Corridor	1	4	Z	3211	Under	91%	25		25
224A	Glasswash	2	4	Z	4973			90		45
225	Equipment Corridor	1	4	Z	3211	Under	93%	25		25
230	Commons	3	6	U	33913			690		230

Appendix D

Make-Up Ventilation Req.

The following table is an example of how the make-up air calculations were performed.



Ventilation Design

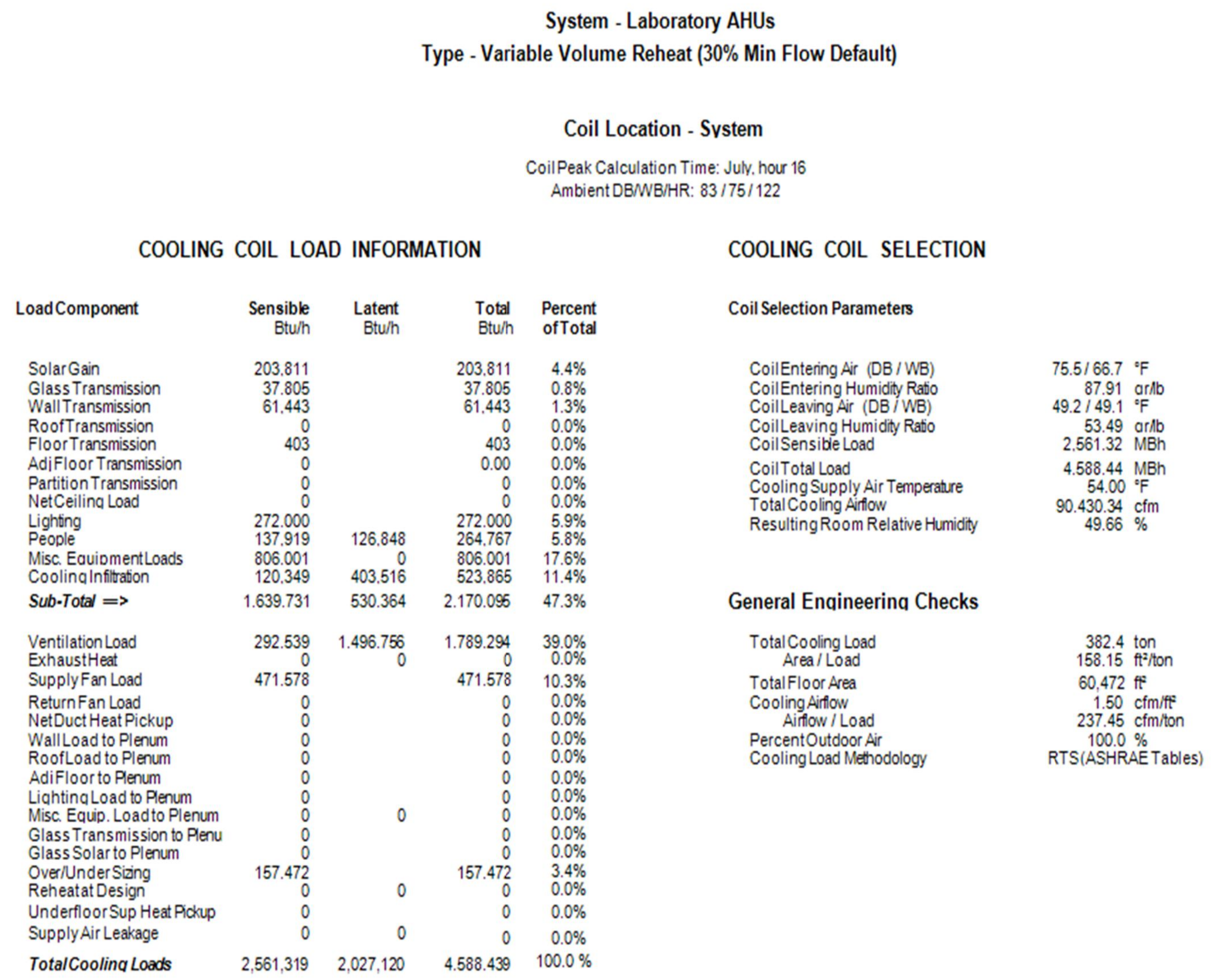
VAV Ventilation System Characteristics

Zone #	Zone Name	Corrected Required Ventilation [CFM]	Combined CFM Requirement	Phoenix/ Envirotec	Number of Units	Inlet Diameter [in.]	Minimum Airflow [CFM]	Max Flow Rate [CFM]	Model
100	Elevator Lobby	0							
101	Vestibule	0							
103	Conference Room	0							
104	Vending	0							
110	Café Storage	0							
111	Coffee	0							
112	Corridor	0							
113	Mechanical	0							
115	Security	0							
116	MDF	0							
122	General Storage	0							
124	W	0							
125	M	0							
200	Elevator Lobby	0	313	Envirotec	1	8	300	1000	SDR
204	Tele-Data	13							
205	Office	0							
206	Office	0							
207	Office	0							
208	Office	0							
209	Office	0							
210	Admin	0							
212	Office	0							
213	Office	0							
214	Conference Room	70							
217	M. Restroom	115							
218	W. Restroom	115							
221	Break Room	0							
222	East Laboratory Control Zone, Lockers, Equipment Alcove, Fume Hood Alcove	3197	3383	Phoenix	2	2(10)	100	2000	Accel II
222C	GLP Lab	107							
222D	Tissue Culture Alcove	37							
222J	Virus Lab	43							
223	West Laboratory Control Zone, Lockers, Protien Lab	3037	3324	Phoenix	2	2(10)	100	2000	Accel II
223B	Tissue Culture Alcove	20							
223C	Microscopy Alcove	55							
223G	Mass Spec Lab	173							
224	Equipment Corridor	16							
224A	Glasswash	0							
225	Equipment Corridor	23							
230	Commons	857	857	Envirotec	1	12	800	2300	SDR

Appendix E

BOD Design Cooling Load

The following is an output summary produced by the TRACE 700 load calculation software



System - Laboratory AHUs
Type - Variable Volume Reheat (30% Min Flow Default)

Coil Location - System

Coil Peak Calculation Time: July, hour 16
Ambient DB/WB/HR: 83 / 75 / 122

COOLING COIL LOAD INFORMATION

Load Component	**Sensible** Btu/h	**Latent** Btu/h	**Total** Btu/h	**Percent of Total**
Solar Gain	203,811		203,811	4.4%
Glass Transmission	37,805		37,805	0.8%
Wall Transmission	61,443		61,443	1.3%
Roof Transmission	0		0	0.0%
Floor Transmission	403		403	0.0%
Adj Floor Transmission	0		0.00	0.0%
Partition Transmission	0		0	0.0%
Net Ceiling Load	0		0	0.0%
Lighting	272,000		272,000	5.9%
People	137,919	126,848	264,767	5.8%
Misc. Equipment Loads	806,001	0	806,001	17.6%
Cooling Infiltration	120,349	403,516	523,865	11.4%
Sub-Total ==>	1,639,731	530,364	2,170,095	47.3%
Ventilation Load	292,539	1,496,756	1,789,294	39.0%
Exhaust Heat	0	0	0	0.0%
Supply Fan Load	471,578		471,578	10.3%
Return Fan Load	0		0	0.0%
Net Duct Heat Pickup	0		0	0.0%
Wall Load to Plenum	0		0	0.0%
Roof Load to Plenum	0		0	0.0%
Adj Floor to Plenum	0		0	0.0%
Lighting Load to Plenum	0		0	0.0%
Misc. Equip. Load to Plenum	0	0	0	0.0%
Glass Transmission to Plenu	0		0	0.0%
Glass Solar to Plenum	0		0	0.0%
Over/Under Sizing	157,472		157,472	3.4%
Reheat at Design	0	0	0	0.0%
Underfloor Sup Heat Pickup	0		0	0.0%
Supply Air Leakage	0	0	0	0.0%
Total Cooling Loads	2,561,319	2,027,120	4,588,439	100.0 %

COOLING COIL SELECTION

Coil Selection Parameters

Coil Entering Air (DB / WB)	75.5 / 66.7	°F
Coil Entering Humidity Ratio	87.91	gr/lb
Coil Leaving Air (DB / WB)	49.2 / 49.1	°F
Coil Leaving Humidity Ratio	53.49	gr/lb
Coil Sensible Load	2,561.32	MBh
Coil Total Load	4,588.44	MBh
Cooling Supply Air Temperature	54.00	°F
Total Cooling Airflow	90,430.34	cfm
Resulting Room Relative Humidity	49.66	%

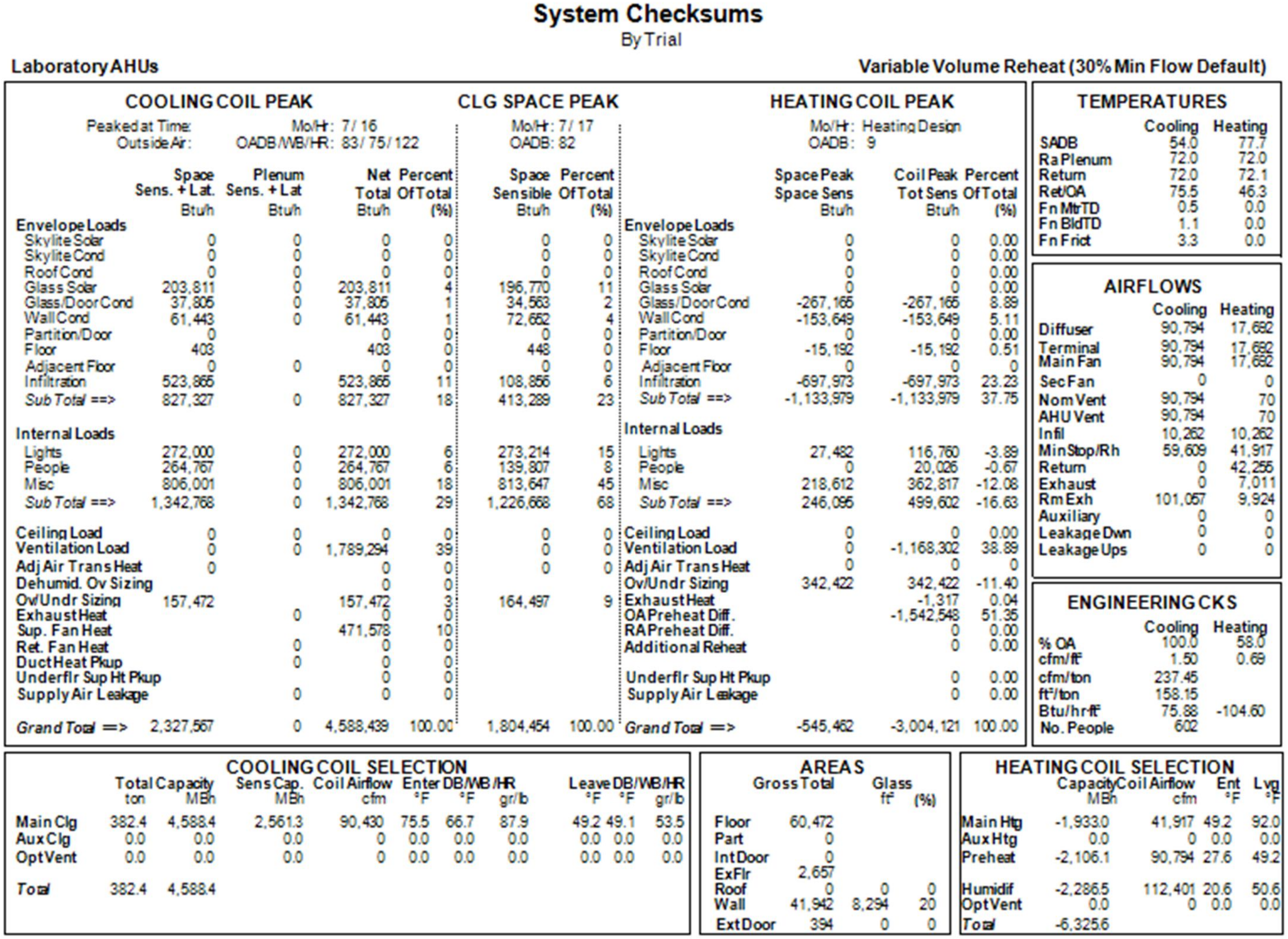
General Engineering Checks

Total Cooling Load	382.4	ton
Area / Load	158.15	ft²/ton
Total Floor Area	60,472	ft²
Cooling Airflow	1.50	cfm/ft²
Airflow / Load	237.45	cfm/ton
Percent Outdoor Air	100.0	%
Cooling Load Methodology	RTS(ASHRAE Tables)	

Appendix F

BOD System Checksums

The following is an output summary produced by the TRACE 700 load calculation software



System Checksums
By Trial

Laboratory AHUs — **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 7/ 16; Outside Air: OADB/WB/HR: 83/ 75/ 122

CLG SPACE PEAK — Mo/Hr: 7/ 17; OADB: 82

	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	0	0	0	0	0
Glass Solar	203,811	0	203,811	4	196,770	11
Glass/Door Cond	37,805	0	37,805	1	34,563	2
Wall Cond	61,443	0	61,443	1	72,652	4
Partition/Door	0		0	0	0	0
Floor	403		403	0	448	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	523,865		523,865	11	108,856	6
Sub Total ==>	827,327	0	827,327	18	413,289	23
Internal Loads						
Lights	272,000	0	272,000	6	273,214	15
People	264,767	0	264,767	6	139,807	8
Misc	806,001	0	806,001	18	813,647	45
Sub Total ==>	1,342,768	0	1,342,768	29	1,226,668	68
Ceiling Load	0	0	0	0	0	0
Ventilation Load	0	0	1,789,294	39	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	157,472		157,472	3	164,497	9
Exhaust Heat		0	0	0		
Sup. Fan Heat			471,578	10		
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 ==>	2,327,567	0	4,588,439	100.00	1,804,454	100.00

HEATING COIL PEAK — Mo/Hr: Heating Design; OADB: 9

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-267,165	-267,165	8.89
Wall Cond	-153,649	-153,649	5.11
Partition/Door	0	0	0.00
Floor	-15,192	-15,192	0.51
Adjacent Floor	0	0	0
Infiltration	-697,973	-697,973	23.23
Sub Total ==>	-1,133,979	-1,133,979	37.75
Internal Loads			
Lights	27,482	116,760	-3.89
People	0	20,026	-0.67
Misc	218,612	362,817	-12.08
Sub Total ==>	246,095	499,602	-16.63
Ceiling Load	0	0	0.00
Ventilation Load	0	-1,168,302	38.89
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	342,422	342,422	-11.40
Exhaust Heat		-1,317	0.04
OA Preheat Diff.		-1,542,548	51.35
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 ==>	-545,462	-3,004,121	100.00

TEMPERATURES

	Cooling	Heating
SADB	54.0	77.7
Ra Plenum	72.0	72.0
Return	72.0	72.1
Ret/OA	75.5	46.3
Fn MtrTD	0.5	0.0
Fn BldTD	1.1	0.0
Fn Frict	3.3	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	90,794	17,682
Terminal	90,794	17,682
Main Fan	90,794	17,682
Sec Fan	0	0
Nom Vent	90,794	70
AHU Vent	90,794	70
Infil	10,262	10,262
MinStop/Rh	59,609	41,917
Return	0	42,255
Exhaust	0	7,011
Rm Exh	101,067	9,924
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	100.0	58.0
cfm/ft²	1.50	0.69
cfm/ton	237.45	
ft²/ton	158.15	
Btu/hr-ft²	75.88	-104.60
No. People	602	

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	382.4	4,588.4	2,561.3	90,430	75.5	66.7	87.9	49.2	49.1	53.5
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	382.4	4,588.4								

AREAS

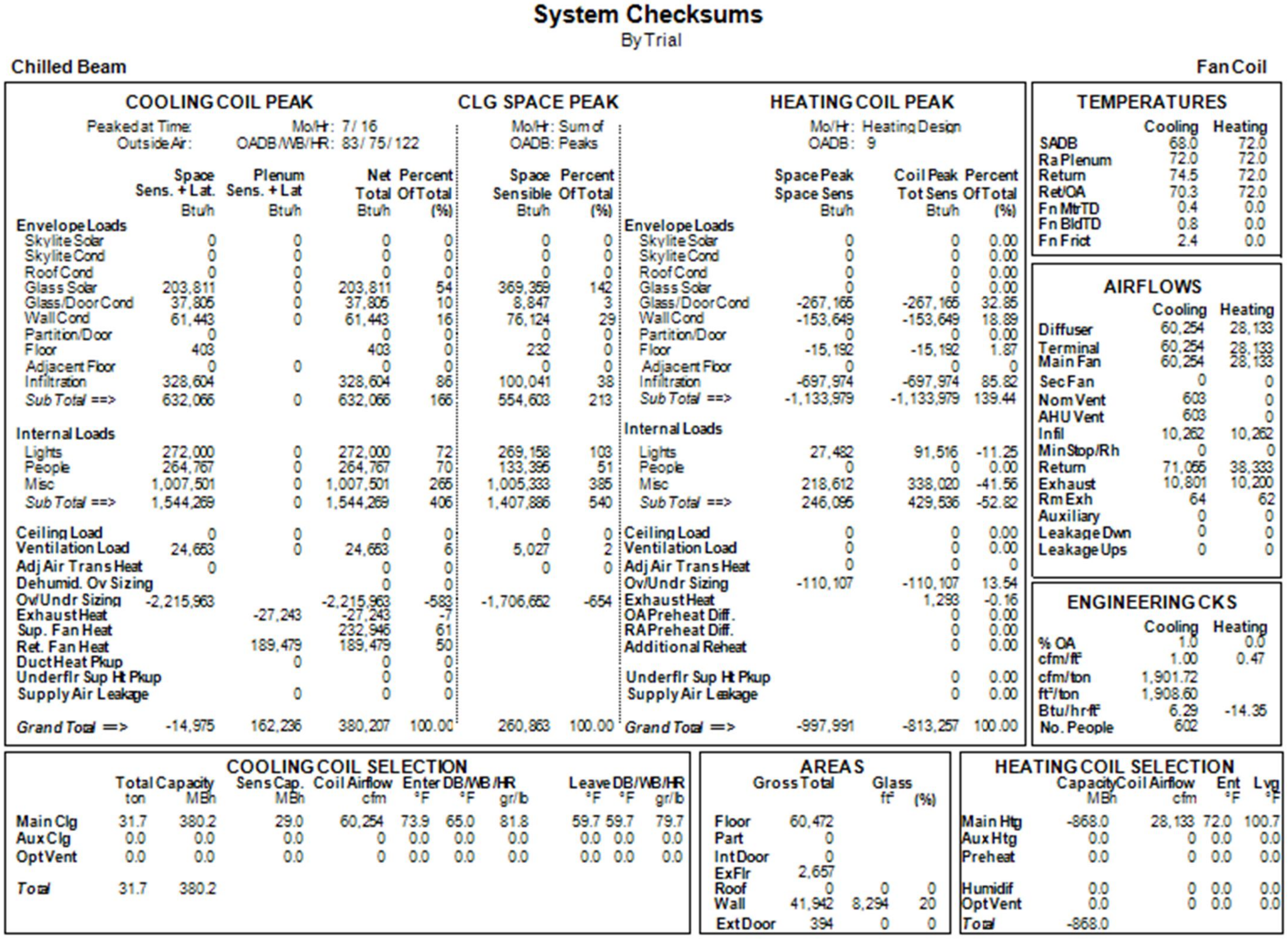
	Gross Total	Glass ft²	Glass (%)
Floor	60,472		
Part	0		
Int Door	0		
ExFlr	2,657		
Roof	0	0	0
Wall	41,942	8,294	20
Ext Door	394	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-1,933.0	41,917	49.2	92.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-2,106.1	90,794	27.6	49.2
Humidif	-2,286.5	112,401	20.6	50.6
Opt Vent	0.0	0	0.0	0.0
Total	-6,325.6			

Appendix G

Re-Design
System Checksums



System Checksums
By Trial

Chilled Beam

Fan Coil

COOLING COIL PEAK

Peaked at Time: Mo/Hr: 7/ 16
Outside Air: OADB/WB/HR: 83/ 75/ 122

CLG SPACE PEAK

Mo/Hr: Sum of
OADB: Peaks

	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	0	0	0	0	0
Glass Solar	203,811	0	203,811	54	369,359	142
Glass/Door Cond	37,805	0	37,805	10	8,847	3
Wall Cond	61,443	0	61,443	16	76,124	29
Partition/Door	0		0	0	0	0
Floor	403		403	0	232	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	328,604		328,604	86	100,041	38
Sub Total ==>	632,066	0	632,066	166	554,603	213
Internal Loads						
Lights	272,000	0	272,000	72	269,158	103
People	264,767	0	264,767	70	133,395	51
Misc	1,007,501	0	1,007,501	265	1,005,333	385
Sub Total ==>	1,544,269	0	1,544,269	406	1,407,886	540
Ceiling Load	0	0	0	0	0	0
Ventilation Load	24,663	0	24,663	6	5,027	2
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	-2,215,963		-2,215,963	-583	-1,706,652	-654
Exhaust Heat		-27,243	-27,243	-7		
Sup. Fan Heat			232,946	61		
Ret. Fan Heat		189,479	189,479	50		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	-14,975	162,236	380,207	100.00	260,863	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design
OADB: 9

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	-267,165	-267,165	32.85
Wall Cond	-153,649	-153,649	18.89
Partition/Door	0	0	0.00
Floor	-15,192	-15,192	1.87
Adjacent Floor	0	0	0
Infiltration	-697,974	-697,974	85.82
Sub Total ==>	-1,133,979	-1,133,979	139.44
Internal Loads			
Lights	27,482	91,516	-11.25
People	0	0	0.00
Misc	218,612	338,020	-41.56
Sub Total ==>	246,095	429,536	-52.82
Ceiling Load	0	0	0.00
Ventilation Load	0	0	0.00
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	-110,107	-110,107	13.54
Exhaust Heat		1,293	-0.16
OA Preheat Diff.		0	0.00
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 ==>	-997,991	-813,257	100.00

TEMPERATURES

	Cooling	Heating
SADB	68.0	72.0
Ra Plenum	72.0	72.0
Return	74.5	72.0
Ret/OA	70.3	72.0
Fn MtrTD	0.4	0.0
Fn BldTD	0.8	0.0
Fn Frict	2.4	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	60,254	28,133
Terminal	60,254	28,133
Main Fan	60,254	28,133
Sec Fan	0	0
Nom Vent	603	0
AHU Vent	603	0
Infil	10,262	10,262
MinStop/Rh	0	0
Return	71,055	38,333
Exhaust	10,801	10,200
Rm Exh	64	62
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	1.0	0.0
cfm/ft²	1.00	0.47
cfm/ton	1,901.72	
ft²/ton	1,908.60	
Btu/hr-ft²	6.29	-14.35
No. People	602	

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	31.7	380.2	29.0	60,254	73.9	65.0	81.8	59.7	59.7	79.7
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	31.7	380.2								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	60,472		
Part	0		
Int Door	0		
ExFlr	2,657		
Roof	0	0	0
Wall	41,942	8,294	20
Ext Door	394	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-868.0	28,133	72.0	100.7
Aux Htg	0.0	0	0.0	0.0
Preheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-868.0			