FINAL REPORT

ON THE INVESTIGATION OF ALTERNATE MECHANICAL SYSTEMS

DALE E. HOUCK | MECHANICAL

CONSULTANT: DR. BAHNFLETH

7 APRIL 2011

PENN STATE UNIVERSITY ARCHITECTURAL ENGINEERING

UNIFIED SCIENCE CENTER

THE UNIVERSITY OF SCRANTON

SCRANTON, PA

DALE E. HOUCK

MECHANICAL OPTION

PROJECT TEAM

OWNER | THE UNIVERSITY OF SCRANTON

ARCHITECT | EINHORN YAFFEE PRESCOTT ARCHITECTURE & ENGINEERING P.C.

CONSTRUCTION MANAGER | QUANDEL ENTERPRISES, INC.

SITE/CIVIL ENGINEER | CECO ASSOC., INC.

LANDSCAPE ARCHITECT | ML BAIRD & CO.

BUILDING STATISTICS

DATES OF CONSTRUCTION | MAY 2009—FALL 2011

SIZE | 200,000 SF TOTAL; 50,000 SF RENOVATIONS

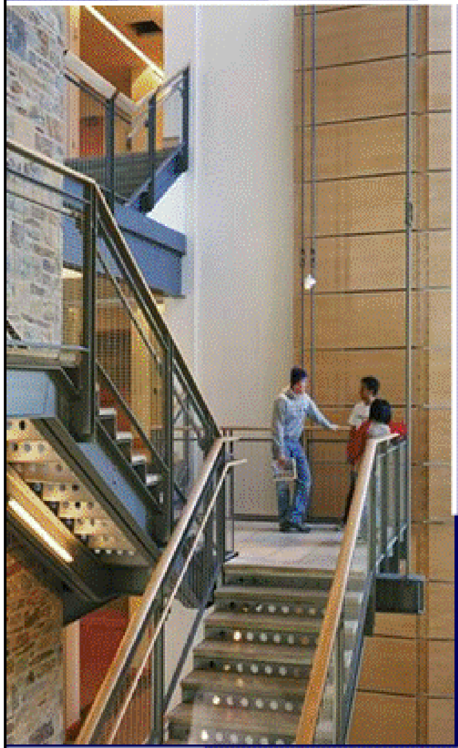
OCCUPANCY TYPE | HIGHER EDUCATION

NO. OF FLOORS | FOUR + ROOFTOP GREENHOUSE

ESTIMATED COST | $73 MILLION

ARCHITECTURE

- Designed according to principles of **Project Kaleidoscope,** an informal alliance to build and sustain strong science, technology, and mathematics undergraduate programs
- Encourages **interdisciplinary collaboration**
- Connects sciences with campus life
- **Modern design** of new construction seamlessly integrates with renovation of existing structure
- Incorporates local materials, natural daylighting and sustainable design to achieve **LEED Silver rating**



STRUCTURE

- 36" **mat-slab foundation** with 3,000 psi concrete
- **Structural steel framing** system with 2" composite floor deck
- **Moment connections** to resist lateral loads

MECHANICAL/ELECTRICAL/PLUMBING

- (4) 52,150 CFM and (1) 5,150 CFM **100% outside air** handling units with **energy recovery wheels**, atomizing fog humidifiers and VAV supply air fans
- (2) 550 ton chillers, (2) 550 ton cooling towers, (3) primary chilled water pumps, (3) condenser water pumps, (8) hot water condensing boilers, (3) primary hot water pumps
- 3.0MVA, 12.4 kV primary supply, 277/480V 3-phase 4-wire secondary
- Emergency **natural gas generator** provides 1000kW/130kVA
- **Energy efficient lighting:** Fluorescent, CFL and LED fixtures with daylight sensors
- Utilization of **efficient water fixtures**

http://www.engr.psu.edu/ae/thesis/portfolios/2011/deh5043

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This report would not have been possible without the tremendous support of many individuals, not only during the course of this thesis project but over the duration of my education at Penn State University. The forces that combined to make this capstone project a reality are too many to name, but I would like to specifically thank the following people for their contributions to the work contained in this document:

The Pennsylvania State University Architectural Engineering Faculty and Staff

Professor William Bahnfleth, *Thesis Advisor*

Professors Kevin Parfitt and Robert Holland, *Thesis Instructors*

Professor Richard Mistrick, *Undergraduate Advisor*

The University of Scranton

David Wilson, *University Architect*

The Quandel Group, Inc.

Michael Krzywicki, *Project Manager*

Einhorn Yaffee Prescott Architecture & Engineering, P.C.

Family and Friends

Linda M. Houck and Dale C. Houck

Olivia Haver

Thank you for all your support!

EXECUTIVE SUMMARY

The purpose of this report is to provide a summary of the existing design of the Unified Science Center, propose alternative design solutions based on the design criteria and objectives established by the owner, and perform in-depth studies of these designs to determine their viability. Updated information from each of the three previous technical reports is included, followed by descriptions of the alternatives to be considered, project methods and research, three mechanical depth studies and four breadth studies.

The Unified Science Center is a 200,000 ft^2 teaching facility on the University of Scranton Campus in Scranton, Pennsylvania. It is intended to achieve LEED Silver certification, and accordingly, its integrated design is geared toward that goal.

After researching many different techniques for laboratory space conditioning and ventilation, three methods were identified as appropriate for this project: a sensible heat recovery wheel to be used in conjunction with the enthalpy wheel already designed; an active chilled beam system to help reduce costs and emissions; and a standard VAV system with terminal reheat to provide a reference for the current design.

After researching and performing analysis on each of these three systems, the following results were determined:

- The addition of heat recovery wheels to the current mechanical system provides a good way to save energy, with a payback period of about 8 years.
- Active chilled beams are also a viable option; though they have some significant drawbacks, they potentially have a payback period of 3-5 years.
- The current design of the HVAC systems outperforms a traditional VAV system not only in terms of annual energy cost, but possibly also initial cost.

In addition to these studies of the building's mechanical systems, breadth studies of the building's architecture/sustainability include light shelf analysis, a solar array study, and an investigation of the feasibility of rainwater harvesting. Solar panels and rainwater harvesting methods are prohibited by unacceptable payback periods, while the use of light shelves is limited by the plenum space required by mechanical systems.

This report concludes that the mechanical systems of the Unified Science Center are extremely well designed and suited to the requirements of the project; still, the redesigns proposed in this report have the potential to save even more energy over the lifetime of the building given the willingness to accept a higher initial cost.

PART 1: SUMMARY OF EXISTING CONDITIONS

PROJECT SUMMARY

The Unified Science Center is an approximately 200,000 ft^2 teaching and research facility on the campus of The University of Scranton in Scranton, Pennsylvania. The building houses university departments of biology, chemistry, computing sciences, physics, electrical engineering, and mathematics, and the program includes offices, classrooms, laboratories, computer rooms, lounges, and a vivarium dedicated to animal research. Through the use of energy efficient and environmentally sound construction methods and equipment specification, the Unified Science Center is designed to earn LEED Silver certification.

New construction accounts for about 150,000 ft^2 and includes four full floors, a partial ground floor, and a rooftop greenhouse. The Unified Science Center is seamlessly integrated with the renovation of an existing campus building. Einhorn Yaffee Prescott A&E, P.C. provided architectural and engineering design, and construction is managed by The Quandel Group, Inc.. The building is scheduled for occupation by Fall 2011.

The Unified Science Center was designed to embody the trends and principles of Project Kaleidoscope, an informal alliance and advocate for 'what works' in building and sustaining strong undergraduate programs in science, technology, engineering, and mathematics. This project will not only accommodate traditional science disciplines but also cross-disciplinary programs, and will serve as a resource for the entire Northeastern Pennsylvania region.

While modern in design, the new structure respects the style and scale of the University of Scranton campus and seamlessly integrates into a renovation of the neighboring St. Thomas Hall. Strategic adjacencies and clusters of offices, classrooms, laboratories, and lounges will encourage interdisciplinary collaboration, and a concourse will link the project to the Campus Commons and Green to connect the sciences with campus life.

Structural steel frames the building, supporting 4½" concrete deck and a glass and masonry façade. The architectural stone veneers are supplied by a local quarry and insulated by rigid polystyrene insulation, while 45% recycled aluminum frames the distinctive curtain walls. Low-E glazing, including ¼" tempered glass and insulated ceramic fritted glass, controls solar gain.

LEED Silver certification is anticipated for this project as a result of its many environmentally friendly attributes. Sustainable features include the use of recycled and regional materials, construction waste management, energy efficient lighting and mechanical systems, low VOC finishes, and efficient water fixtures.

MECHANICAL SYSTEMS DESIGN CRITERIA AND OBJECTIVES

The primary objective of any HVAC system is to provide proper ventilation and thermal comfort to the occupants of the building by maintaining specified ventilation rates and a comfortable temperature and humidity level. In doing so, it is also desirable to minimize operational costs for the life cycle of the building.

Given the nature of the spaces in the Unified Science Center, indoor air quality is a significant concern; the number of laboratories demands that the HVAC system be capable of providing a large amount of outdoor air to properly ventilate spaces, rapidly clear rooms of lab spills and vapors, and minimize the recirculation of potentially dangerous contaminants.

While such safety concerns primarily drive the design of the HVAC system, the Unified Science Center is also subject to a variety of other factors influencing mechanical systems design. Large equipment loads resulting from laboratory facilities and computers, in combination with considerable design occupancy loads, provide significant internal loads to be dealt with during the cooling season. In addition, generous fenestration subjects large portions of the building to significant solar gain, making perimeter spaces critical.

The architectural layout of the building is conducive to efficiency of HVAC layout; the L-shaped building lends itself to a centralized HVAC system on the penthouse level, and each floor is generally laid out identically, with offices, laboratories, and classrooms occupying similar positions on each level.

Finally, the owner's design intent is to achieve LEED Silver certification, making the Unified Science Center the first LEED certified building on the University of Scranton campus. Mechanical system efficiency is critical in pursuit of this goal, and accordingly should be given considerable emphasis in the design of HVAC systems.

DESIGN CONDITIONS

The selection and design of HVAC systems is heavily influenced by indoor and outdoor design conditions. Northeastern Pennsylvania experiences harsh winters and hot summers, as evidenced by the ASHRAE design conditions shown in Table 1.

Table 1: ASHRAE Design Conditions

ASHRAE Design Conditions – Scranton, PA		
	Dry Bulb Temperature (˚F)	Wet Bulb Temperature (˚F)
Cooling	88.9 (0.4%)	72.1 (0.4%)
Heating	3.5 (99.6%)	-

Indoor design conditions vary according to season and occupancy, while the vivarium maintains its own requirements as a result of the unique nature of the space. Setpoints were taken from the project documentation, and are shown in Table 2.

Table 2: Indoor Design Conditions

Indoor Design Conditions		Summer		Winter	
		DBT (˚F)	RH (%)	DBT (˚F)	RH (%)
Offices, Classrooms, Laboratories	Occupied	75	55	70	30
	Unoccupied	78	60	65	25
Vivarium	Occupied/Unoccupied	72	55	72	50

EQUIPMENT SUMMARY

Based upon the design requirements, objectives, and conditions, the engineers devised an MEP system that responds directly to the specificities of this project. With indoor air quality being the primary concern, 100% outside air is provided to the building with (4) coupled 50,000 CFM AHUs utilizing energy recovery wheels and variable frequency drives. A similar 5,150 CFM unit is dedicated to vivarium spaces. Table 3 provides a summary of the AHUs.

Table 3: Summary of Air Handling Units

Air Handling Units				
	Total Fan CFM	Total Supply CFM	Heating Coil Capacity (MBH)	Cooling Coil Capacity (MBH)
AHU 1	52,626	50,000	3430.6	5364
AHU 2	52,626	50,000	3430.6	5364
AHU 3	52,626	50,000	3430.6	5364
AHU 4	52,626	50,000	3430.6	5364
AHU 5	5,746	5,150	323	525.5

Two water-cooled, electric motor driven, centrifugal chillers are to be used in the Unified Science Center. A summary of this equipment is found in Table 4.

Table 4: Summary of Water-Cooled Chillers

Water-Cooled Chillers							
	Capacity (Tons)	Efficiency		Evaporator (˚F)	Condenser (˚F)	Electrical	
		EER (BTU/W-h)	NPLV (kW/Ton)	EWT/LWT	EWT/LWT	MCA	MOCP
CH 1	550	0.548	0.344	56/44	85/95	545	800
CH 2	550	0.548	0.344	56/44	85/95	545	800

Two rooftop cooling towers serve the chillers, and are summarized in Table 5:

Table 5: Summary of Cooling Towers

Cooling Towers					
	Nominal Capacity (Tons)	Design WBT (˚F)	EWT (˚F)	LWT (˚F)	Fan Motor (HP)
CT 1	550	76	95	85	25
CT 2	550	76	95	85	25

Heating hot water is provided by (8) natural gas fired condensing boilers located on the penthouse level. Each boiler operates identically; a summary of a typical boiler is provided in Table 6:

Table 6: Summary of Natural Gas Boilers

Natural Gas Fired Boilers (typ.)							
	Gas Input (MBH)	Net IBR Output (MBH)	EWT (˚F)	LWT (˚F)	Min/Max Flow (GPM)	Efficiency (%)	Electrical FLA
B-x	1999	1760	150	180	25/120	87	11

Information pertaining to end suction pumps is summarized in Table 7:

Table 7: Summary of Water Pumps

Pumps						
	Service	GPM	Head (ft)	BHP	HP	RPM
P 1	Chilled Water	1100	95	33.19	40	1760
P 2	Chilled Water	1100	95	33.19	40	1760
P 3	Chilled Water	1100	95	33.19	40	1760
P 4	Condenser Water	1650	65	30.75	40	1760
P 5	Condenser Water	1650	65	30.75	40	1760
P 6	Condenser Water	1650	65	30.75	40	1760
P 7	Heating Hot Water	480	90	14.24	20	1760
P 8	Heating Hot Water	480	90	14.24	20	1760
P 9	Heating Hot Water	480	90	14.24	20	1760

SYSTEMS OPERATIONS SUMMARY

Airside

AHUs 1, 2, 3, and 4 are each 50,000 CFM 100% outside air handling units with energy recovery wheels, hot water coils, chilled water coils, atomizing fog humidifiers and variable volume supply air fans. They serve all areas of the building, including wet labs, dry labs, classrooms, and offices, and are scheduled to operate 24 hours a day. AHUs 1 and 2 are coupled and serve the south leg of the building, while AHUs 3 and 4 operate similarly to serve the rest of the building. AHU 5 is the same type of unit as the other four, and supplies the ground floor vivarium with 5,150 CFM. Figure 2 shows the areas served by each AHU.

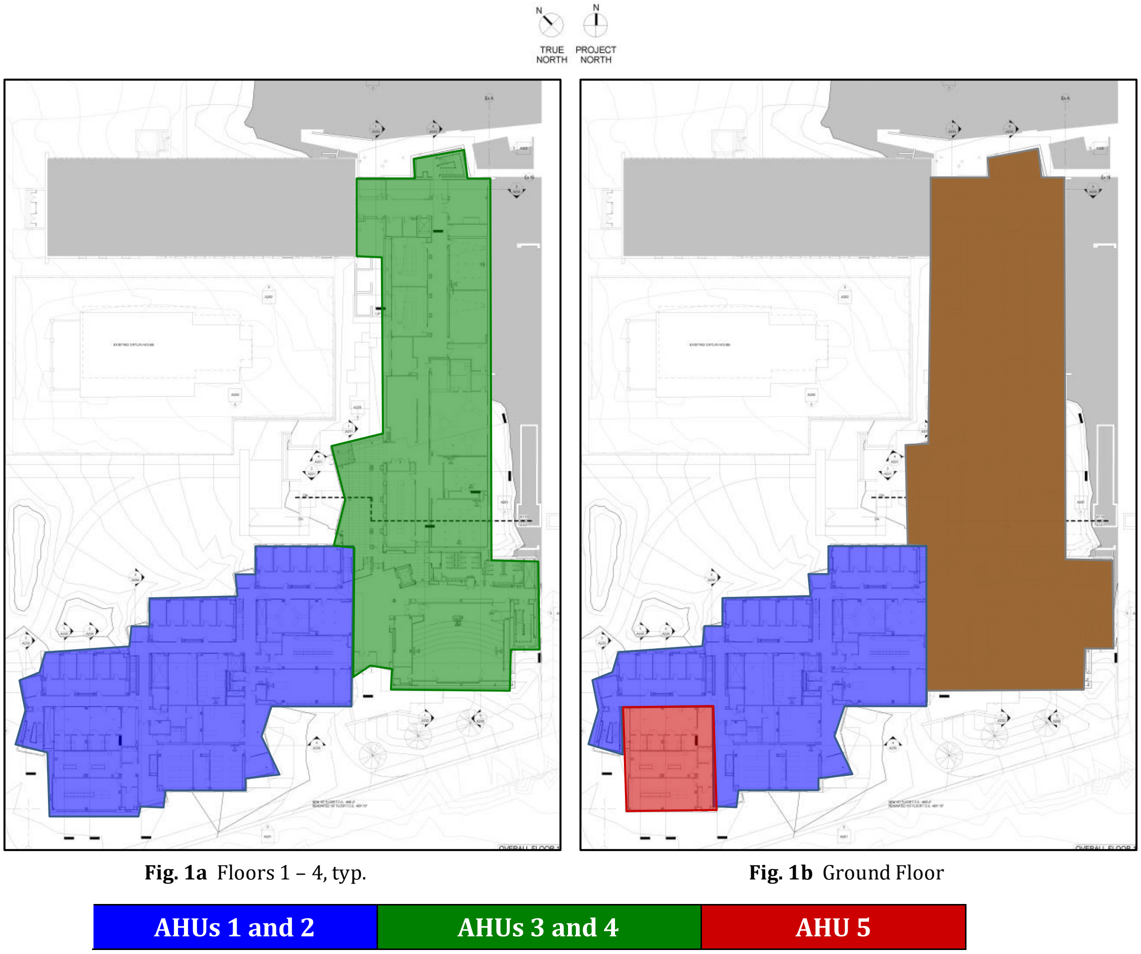


Fig. 1a Floors 1 – 4, typ.

Fig. 1b Ground Floor

Fig. 1: Areas Served by Each AHU

Figure 2 shows the overall airflow diagram for the 5 air handling units. Not shown in this figure due to space constraints is the outdoor air supplied to each AHU.

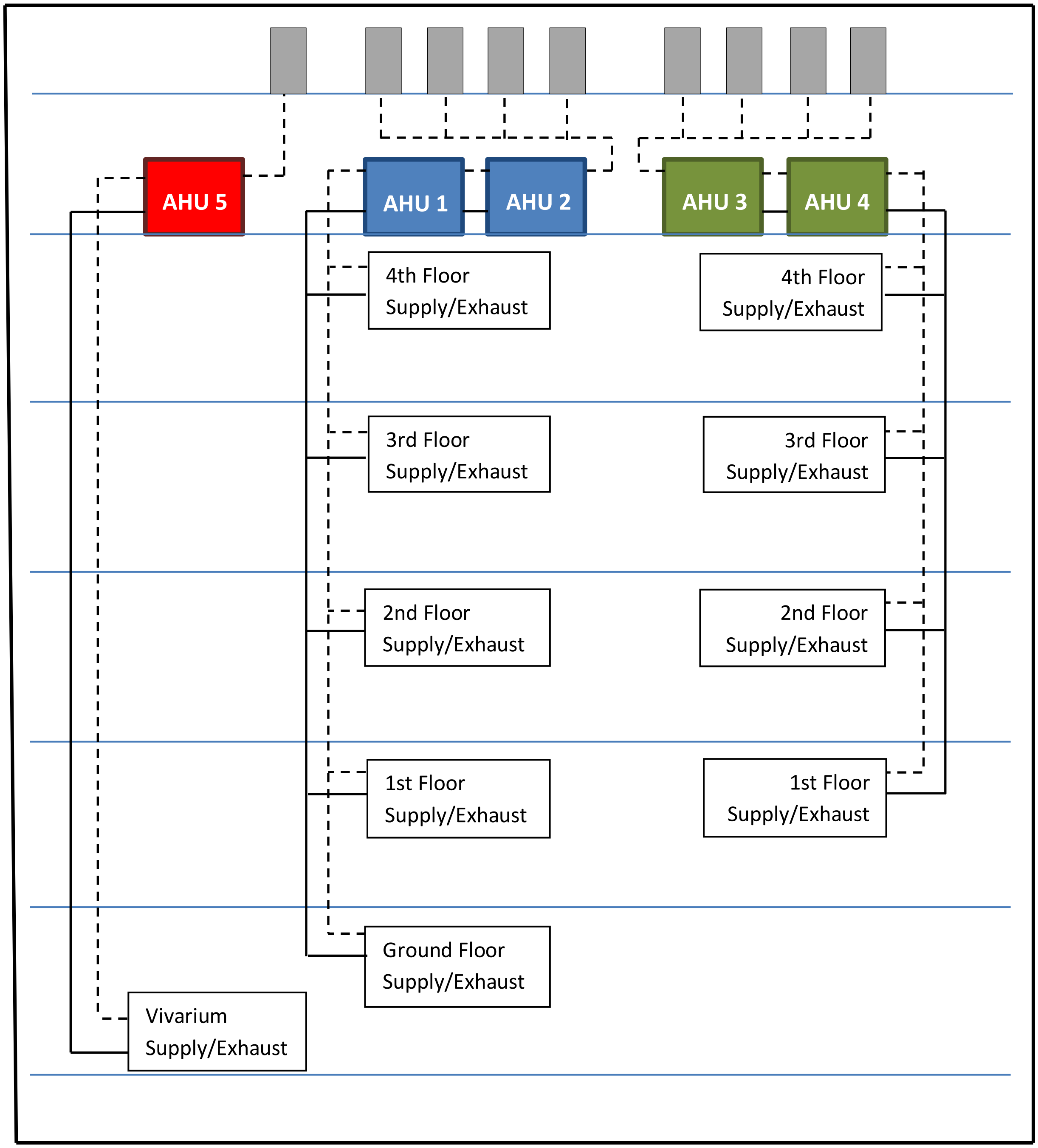


Fig. 2: Overall Airflow Diagram

Each AHU is equipped with a variable frequency drive to modulate supply fan speed and maintain static pressure above 1.5" of water. The exhaust fans operate in unison with the supply fans, and also have variable frequency drives. To maintain the setpoints (refer to Table 2), the energy recovery wheels (ERWs) are the primary source of heating and cooling; the hot water coil and chilled water coil will provide supplemental heating and cooling if the ERWs cannot maintain the discharge temperature setpoint. The Building Automation System (BAS) modulates the ERW speed, hot water valve, and chilled water valve to achieve the desired temperature. In the case of cold temperatures (less than 40 ˚F), the hot water valve will open proportionally to temperature, and the ERW speed is reduced to prevent frost buildup.

Figures 3, 4, and 5 show the typical configuration of each AHU:

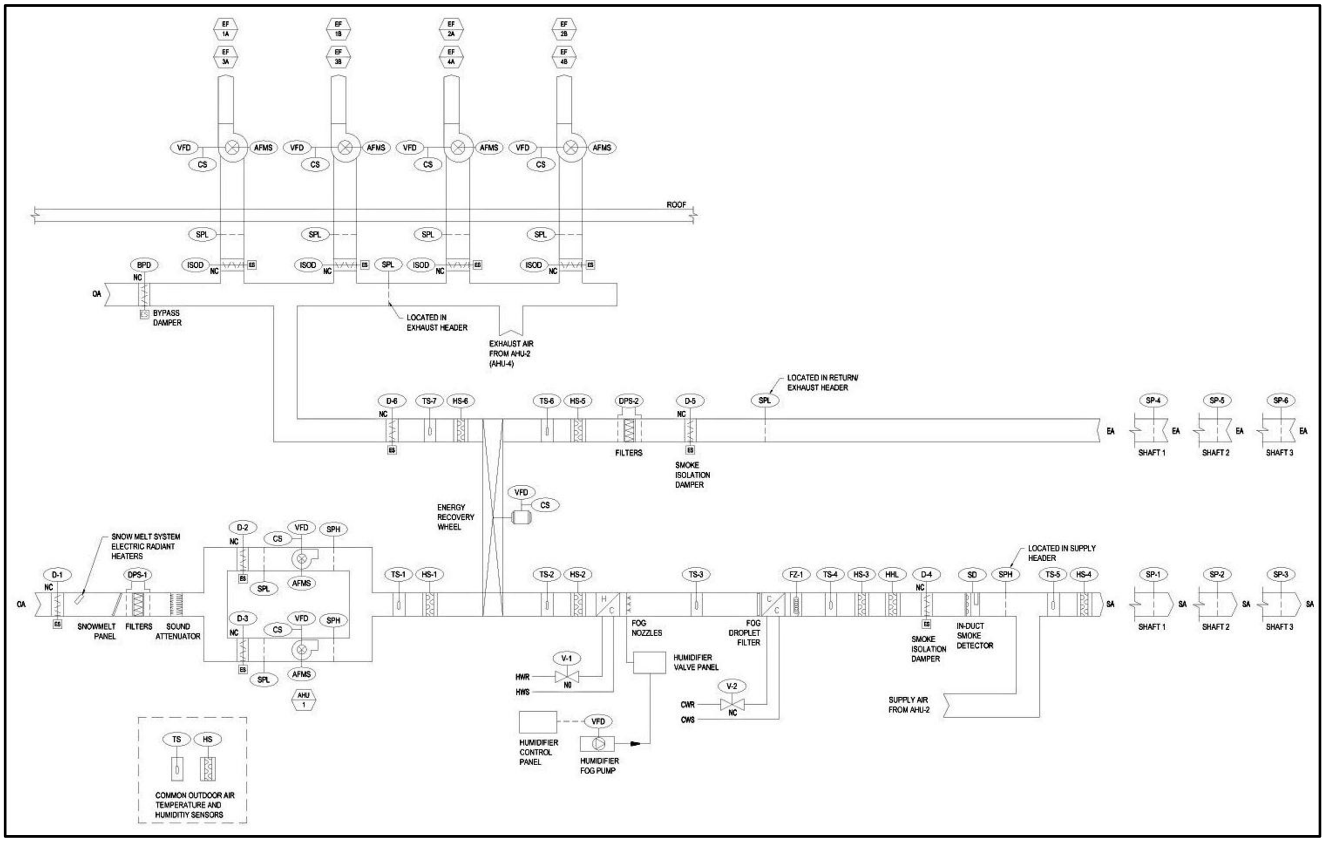


Fig. 3: Typical AHU Configuration

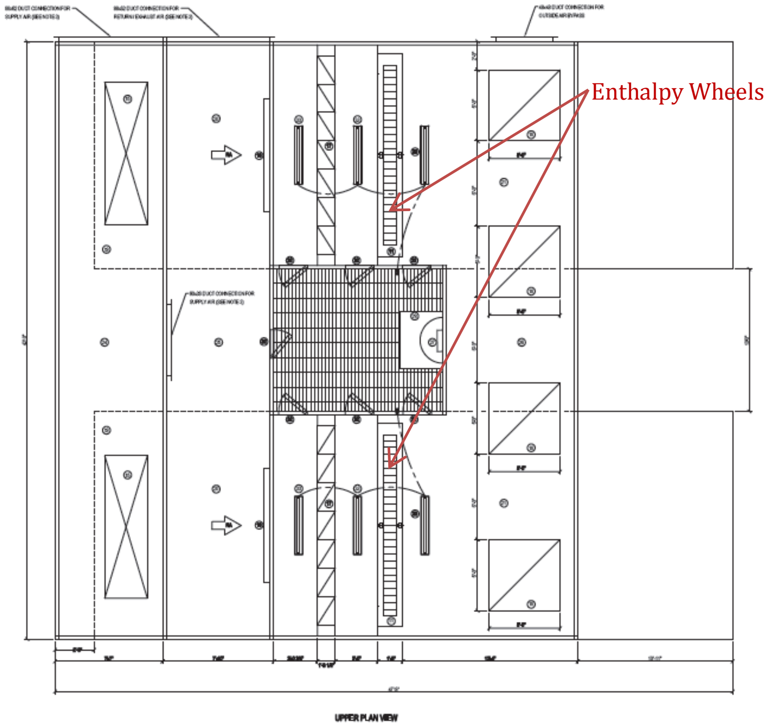


Fig. 4 Upper Plan View (Return/Exhaust Air) of Dual AHU Configuration

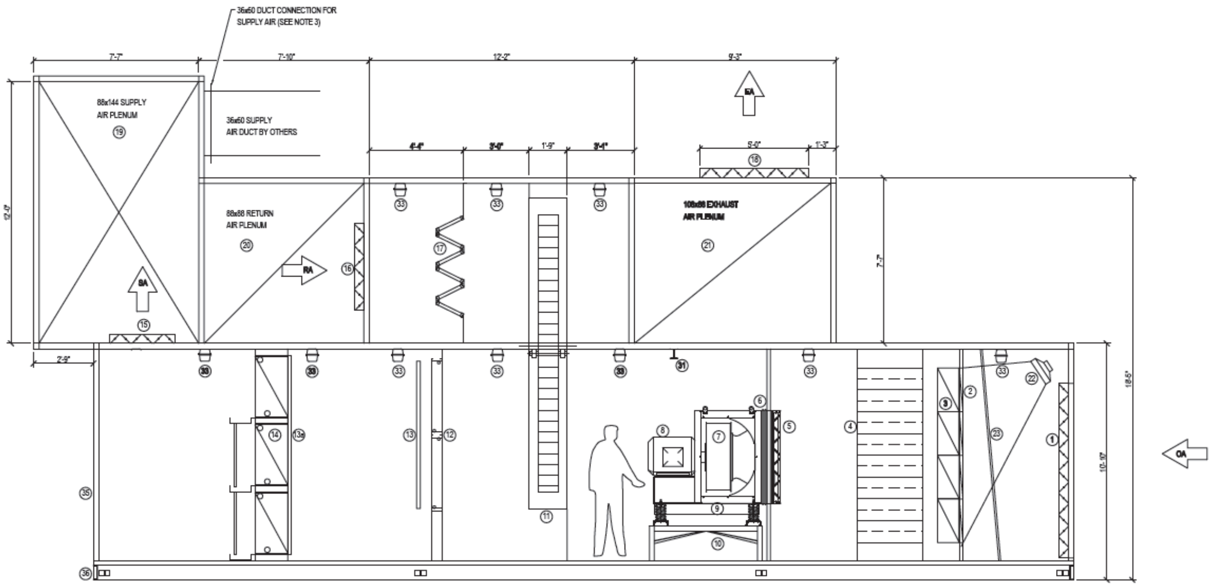


Fig. 5 Section of Typical AHU with Energy Recovery Wheel and 100% Outdoor Supply Air

Waterside

The chilled water system consists of (2) 550 ton chillers, (2) 550 ton cooling towers, (3) primary chilled water pumps and (3) condenser water pumps. The variable frequency drive pumps are configured such that any pump can serve either chiller or either tower. The towers are also configured such that either tower can serve either chiller; this provides system redundancy in the event of equipment failure or maintenance shutdown.

The chilled water plant starts whenever any chilled water valve exceeds 5% open for more than 5 minutes and the outside air temperature is above 57 ˚F. Below 55 ˚F, chiller operation will cease. The chilled water pumps start at minimum speed and increase to achieve the building system differential pressure of 12 psig. Once building pressure is achieved, the pump will modulate to maintain system pressure. The condenser water pumps start at minimum speed and increase to 50% until the chiller starts. If the differential temperature increases above the setpoint, the pump speed increases, with the reverse occurring with a decrease in differential temperature. The condenser water pump will maintain a minimum of 50% speed while the chiller is operating.

The chilled and condenser water pumps operate in a lead/lag/standby fashion, with the lead pump operating with the lead chiller. The cooling tower bypass valve modulates to maintain the condenser water supply temperature minimum setpoint to the chiller. Both cooling towers operate together to serve the operating chiller(s). At the end of the cooling season, the chilled water plant is shut down and the cooling towers drained; a 61.8 ton air-cooled winter/standby chiller is to be used if necessary during the heating season.

The heating system consists of (8) hot water condensing boilers and (3) primary hot water pumps with individual variable frequency drives. At least one building heating hot water pump shall operate at all times; the pumps operate in a lead/lag/standby fashion. At start-up, the lead pump increases until the system differential pressure is reached, and continues to modulate to maintain system pressure. When the lead pump speed remains greater than 95% for more than 5 minutes, the lag pump starts and increases to match the lead pump speed and then runs in unison with the lead pump to maintain the set point. A Boiler Management System modulates the firing rates of all operating boilers to maintain the supply hot water setpoint.

Figures 6 and 7 show the chilled and hot water flow diagrams, respectively.

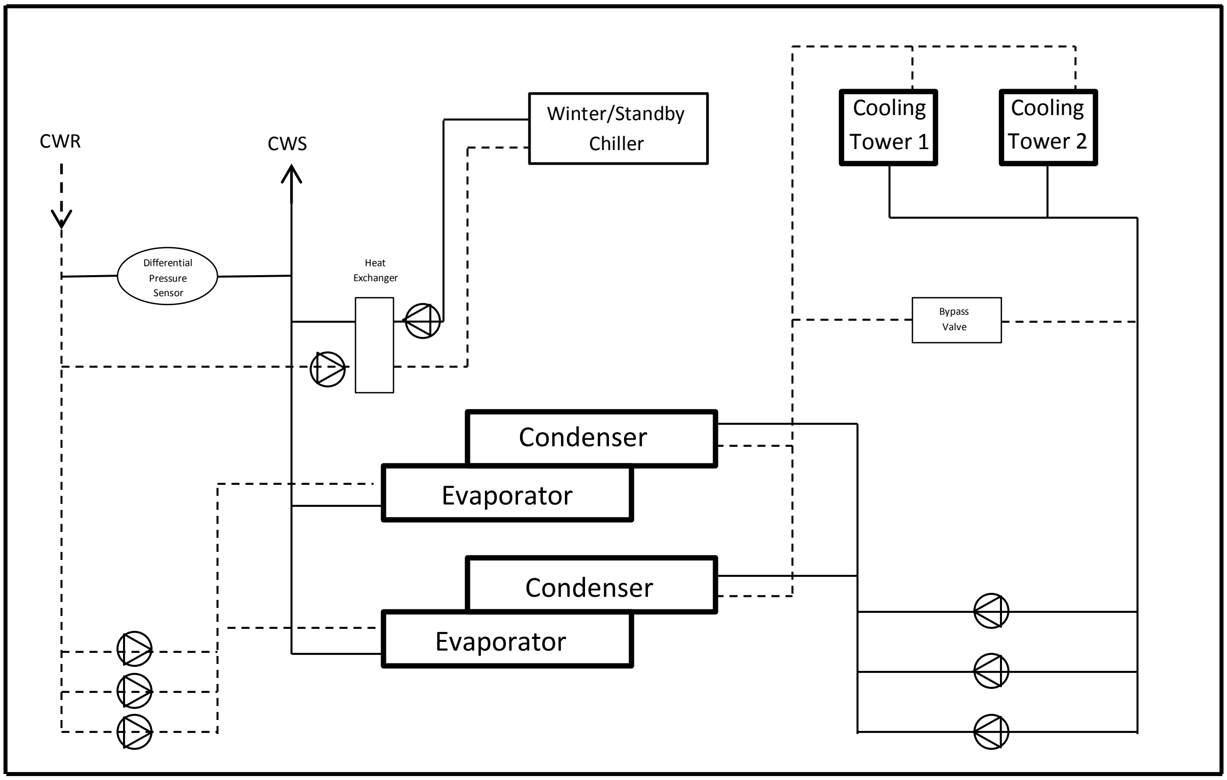


Fig. 6: Chilled Water Diagram

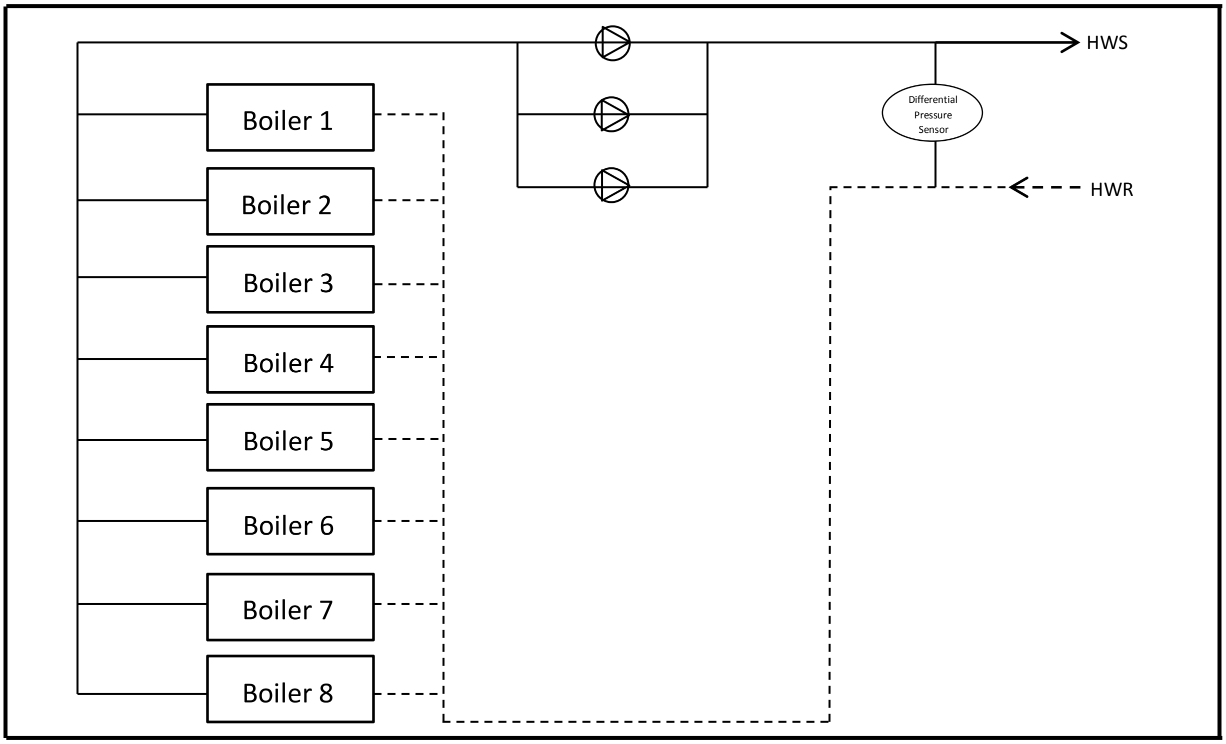


Fig. 7: Hot Water Diagram

LOST USABLE SPACE

Usable space lost to mechanical systems is shown by Table 8. These figures include both mechanical rooms and duct shaft area. Mechanical rooms are located on the ground floor and penthouse level. The total area lost to mechanical systems is estimated to be 17,800 ft^2, or about 9% of the total building area.

Table 8: Lost Usable Space

Area Lost to Mechanical Systems	
Floor	**Lost Area (ft^2)**
Ground Floor	**5,567**
First Floor	**235**
Second Floor	**235**
Third Floor	**235**
Fourth Floor	**235**
Penthouse	**11,279**
Total Area Lost	**17,800**
Percentage of GSF	**9%**

MECHANICAL SYSTEMS FIRST COST

Detailed information pertaining to the first cost of the mechanical systems for the Unified Science Center was not made available for this report. For buildings of this type, mechanical systems typically account for 15-25% of the total first cost. Since the Unified Science Center will cost a total of $73 million to build, this estimation produces a value between $11 and $18 million. However, the sophistication of the design, which includes energy recovery wheels and high-efficiency boilers and chillers, is likely to produce a first cost greater than this estimate.

SUMMARY OF COMPLIANCE WITH ASHRAE STANDARD 62.1

ASHRAE Standard 62.1 specifies the minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to minimize the potential for adverse health effects. It applies to all indoor or enclosed spaces that people may occupy.

The Unified Science Center is seeking Leed Silver Certification, and accordingly its HVAC systems are of a particularly high quality to achieve sophistication of operation with the use of energy efficient systems. It features 5 AHUs with variable frequency drives, desiccant energy recovery wheels, and atomizing fog humidifiers to economically serve a wide variety of spaces including offices, classrooms, laboratories, and computer/server rooms with 100% outside air.

Analysis of Sections 5 and 6 show that **the systems as designed will fully comply with ASHRAE Standard 62.1**, and in many cases greatly exceed the requirements.

Section 5 – Systems and Equipment

Section 5 specifies the systems and equipment recommended under Standard 62. It covers a number of important issues including the prevention of mold growth, measures to prevent re-entry of contaminated air, and particulate filtration. Analysis of this building relative to each of the recommendations of Section 5 shows that **compliance is entirely met**, and in many cases exceeds the minimum requirements.

Compliance

5.1: Natural Ventilation **N/A**

None of the windows in the building are operable, so natural ventilation is not a consideration.

5.2: Ventilation Air Distribution **Yes**

Designed to provide 100% outside air, ventilation air distribution is not a concern for the mechanical system of this building.

5.3: Exhaust Duct Location **Yes**

Exhaust ducts conveying potentially harmful contaminants, such as toilets, kitchens, and laboratories, are negatively pressurized relative to the spaces through which they pass and/or properly sealed from leakage; they exhaust directly to the rooftop, away from occupied spaces and air intakes.

5.4: Ventilation System Controls **Yes**

Direct Digital Control (DDC) controls and field panels operate as a fully integrated extension of the existing campus Building Automation System (BAS). Input devices include temperature sensors, carbon dioxide sensors, airflow measurement devices, differential pressure transmitters, power monitoring devices, and status and safety switches. Output devices include relays, actuators, and control dampers and valves.

5.5: Airstream Surfaces **Yes**

The building primarily uses sheet metal ducts and fasteners, which are exempt from this section. Airstream surfaces in non-sheet metal ducts are specified with fibrous-glass duct liner to comply with NFPA 90A – *Standard for the Installation of Air Conditioning and Ventilating Systems* and NAIMA AH124 – *Fibrous Glass Duct Liner Standard.* These standards require the prevention of erosion and mold/bacteria growth inside the ducts.

5.6: Outdoor Air Intakes **Yes**

The location of outdoor air intakes relative to exhaust fans was compared with recommendations in ASHRAE Standard 62.1 Table 5.1: *Air Intake Minimum Separation Distance.* All the air handling units and air intakes are located on the penthouse level, while exhaust fans are located on the roof level above, maintaining or exceeding the recommended separation distance from air intakes. All air handling units are designed with drain systems to manage rain and snow entrainment. Bird screens are included to prevent nesting.

5.7: Local Capture of Contaminants **Yes**

All potential contaminants are exhausted directly to the roof, satisfying this requirement.

5.8: Combustion Air **Yes**

Boilers, laboratories, kitchens, and generators requiring combustion air are supplied with sufficient air for combustion; all products of combustion are exhausted directly outdoors, thus complying with the requirements of this section.

5.9: Particulate Matter Removal **Yes**

All air handling units contain filters ranging in efficiency from MERV 8 to MERV 14, thus exceeding the minimum requirements of this section.

5.10: Dehumidification Systems **Yes**

There are no systems beyond the AHUs to provide dehumidification in the building; the setpoints for various spaces range from 50% to 60% RH, below the 65% maximum in this section. All spaces meet the exfiltration requirements.

5.11: Drain Pans

Yes

All the water coils are specified to have drain pans that comply with this Standard; they are typically double wall, continuously welded, 12 – 18 gage 304 stainless steel.

5.12: Finned-Tube Coils and Heat Exchangers

Yes

All finned-tube heat exchangers are used for heating only, so this requirement does not apply.

5.13: Humidifiers and Water-Spray Systems

Yes

High-pressure atomizing fog humidifiers are contained within the air handling units, and utilize water of a quality comparable to that of potable water.

5.14: Access for Inspection, Cleaning, and Maintenance

Yes

All ventilation equipment is to be built with adequate space for inspection, cleaning, and maintenance. Convenient access is provided for each component of the air distribution system, with access doors ranging in size from 8”x5” to 25”x17”.

5.15: Building Envelope

Yes

Wall construction features a fluid-applied air and vapor barrier membrane allowing 0.20 perm, which is reinforced with a flexible membrane consisting of rubberized asphalt bonded with high density polyethylene film to allow a maximum permeance rating of 0.05 perm. Interior pipes and ducts are insulated to prevent condensation, and all exterior joints, seams, and penetrations are properly sealed to limit infiltration.

5.16: Buildings with Attached Parking Garages

Yes

There is no parking structure attached to the Unified Science Center.

5.17: Air Classification and Recirculation

Yes

Classification of exhaust air varies by space, but the 100% outside air system avoids issues that might arise with recirculation.

5.18: Requirements for Buildings Containing ETS Areas & ETS-Free Areas

Smoking is not permitted within the Unified Science Center; outdoor tobacco smoke should not affect the indoor air quality given that the air intakes are located on the roof. **Yes**

Section 6 – Ventilation Rate Procedure

Section 6 prescribes the rate at which ventilation air must be delivered to a space and recommends various means to condition that air based on outdoor air quality criteria for acceptable ventilation. The Ventilation Rate Procedure determines acceptable outdoor air intake rates based on space type/application, occupancy level, and floor area. Details regarding the procedure can be found in the Appendix.

As 100% outdoor air units, all the AHUs easily satisfy the requirements set forth by Standard 62.1. Assumptions made during analysis about space types and occupancy using default ASHRAE data may have underestimated the production of contaminants, especially in the cases of advanced laboratories and other unique spaces. Occupancy data was estimated using Table 6-1 when not specified in the project documentation. Outdoor air rate values were also taken from Table 6-1. Areas and design ventilation rate values were read from the drawings provided by the architectural engineers.

In Technical Report 1 – *Compliance Evaluation of ASHRAE Standards 62.1 and 90.1*, an analysis was performed to verify compliance with ASHRAE Standard 62.1 – *Ventilation for Acceptable Indoor Air Quality*. This report concluded that the systems and equipment of the Unified Science Center are properly designed to achieve acceptable indoor air quality, and in many cases exceed the requirements set forth by ASHRAE.

For all three AHUs analyzed, the (outdoor) supply air as designed is approximately 5 times the required outdoor air. The Unified Science Center's ventilation system as designed will **fully comply** with Section 6.

While detailed analysis can be found in Technical Report 1 and Appendix B of this report, a summary of its results is given by Table 9.

Table 9: Summary of Compliance with ASHRAE Std. 62.1, Section 6

	Capacity (CFM)	Required OA (CFM) Vot	Design OA (CFM) Vpz	Oversupply (CFM)	Max Zp	Ev	Compliance
AHU-5	5,150	870	5050	4180	0.247	0.8	YES
AHUs 1 and 2	105,252	21,506	102,475	80969	0.446	0.7	YES

SUMMARY OF COMPLIANCE WITH ASHRAE STANDARD 90.1

ASHRAE Standard 90.1 provides minimum requirements for the energy-efficient design of buildings except low-rise buildings. This Standard focuses on the effects of the building envelope, HVAC systems, and electrical design on energy efficiency.

The Unified Science Center utilizes a number of state of the art design features, systems, and equipment to curb energy use and achieve LEED Silver certification. Daylighting, High performance materials, and efficient equipment contribute to **significant compliance** with Standard 90.1. The majority of critical systems exceed the minimum requirements.

Section 5 – Building Envelope

Section 5 specifies requirements for the building envelope. It covers a number of important factors including climate, insulation, and fenestration, and prescribes performance criteria for energy efficiency.

The Unified Science Center's building envelope is distinctive, with large curtain walls and local stone. In accordance with LEED criteria, the building envelope as a whole is of a superior quality in terms of thermal transfer and energy efficiency.

5.1.3: Envelope Alterations

This project includes approximately 50,000 ft^2 of renovation and a connection with the new structure. The alterations being performed are largely exempt from this requirement and otherwise comply fully.

5.1.4: Climate

ASHRAE classifies Scranton, PA as in Climate Zone 5, Subtype A – Cool/Humid:

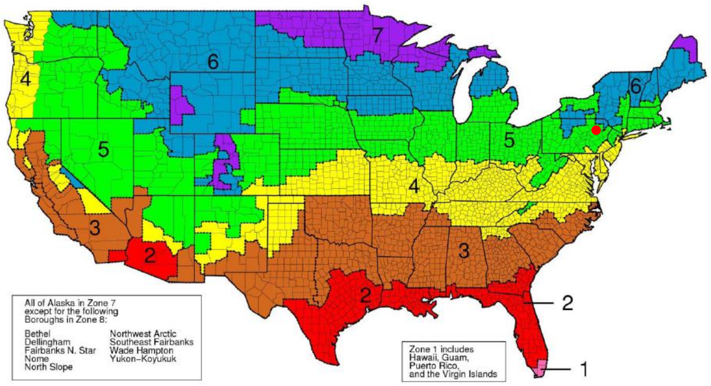


Fig 8: Fig. B-1, ASHRAE Standard 90.1 Appendix B

5.2.1: Compliance

The large curtain walls of the Unified Science Center make up about 30% of the gross wall area, thus complying with the requirements. With the use of double paned low-E fritted spandrel glass and architectural louvers, the curtain wall system has excellent thermal performance.

Table 10: Summary of Compliance with ASHRAE Std. 90.1, Section 5.2.1

	Area of Glass (SF)	Gross Wall Area	% of Glass	Compliance
North Façade	600	4256	12	YES
East Façade	1,176	2,800	30	YES
West Façade	1280	3424	27	YES
South Façade	3285	5205	39	YES
Total	6341	15685	29	YES

5.4: Mandatory Provisions

All joints in the fenestration, doors, and structure will be sealed to limit infiltration. All building entrances are protected by vestibules or otherwise exempt from this provision.

The roofing system for the Unified Science Center consists of fully adhered single-ply PVC membrane, water-resistant gypsum substrate, tapered rigid isocyanurate foam insulation, and a laminate polyethylene vapor retarder on Type B metal deck. The PVC membrane is white in color to comply with solar reflectance values determined by LEED performance criteria.

The stone veneers are insulated by rigid polystyrene insulation.

Specific U-values and Solar Heat Gain Coefficients for glazing and roofing were not given in the documentation, but given the nature of this project it is assumed they are high performance. The roof insulation is estimated to be approximately R-30 based on the typical thickness of insulation.

Section 6: Heating, Ventilating and Air Conditioning

All of the heating, ventilation, and air conditioning equipment in the Unified Science Center is oriented toward energy efficiency and quality of operation. LEED Silver performance criteria influences much of the design and equipment typically meets or exceeds the requirements of Standard 90.1. Using Variable Frequency Drives, Variable Air Volume terminal boxes, and energy recovery, the HVAC systems are designed to comply with Standard 90.1.

There are (2) 550 ton chillers, (2) 550 ton cooling towers, (3) primary chilled water pumps, several gas fired condensing boilers. Energy performance in most areas satisfy the requirements of Section 6. The condensing boilers run at 87% efficiency, well above the ASHRAE minimum of 80%.

In addition to the high performance of each individual component of the HVAC systems, Direct Digital Controls are integrated into an existing campus Building Automation System to provide optimal air quality and thermal comfort.

LEED-NC ASSESSMENT

The Unified Science Center was designed to achieve LEED Silver certification. Throughout the building's design, many techniques involving project management and all building systems were used to accumulate points toward this goal. This report will focus on the aspects of design that are directly related to the building's mechanical systems. The following assessment is based on LEED 2009 for New Construction and Major Renovations.

Energy and Atmosphere

Credit?

Prerequisite 1: Commissioning of Building Systems — **Yes**

This prerequisite requires commissioning and appropriate documentation for all HVAC systems, in addition to many other building systems. The Unified Science Center is specified for commissioning and documentation of all HVAC systems.

Prerequisite 2: Minimum Energy Performance — **Unknown**

This prerequisite establishes a minimum level of energy efficiency for building systems to reduce environmental and economic impacts associated with excessive energy use. It offers three options for compliance; the Unified Science Center, at 200,000 ft^2, is ineligible to use options two or three, and thus must comply with option one: completion of an energy simulation model that shows performance of 10% over an ASHRAE Standard 90.1 established baseline. Information about energy models performed by the engineers was unavailable at the time of this report, but as this is a prerequisite, it is assumed to have been met.

Prerequisite 3: Refrigeration Management — **Yes**

This prerequisite prohibits the use of CFC-based refrigerants in HVAC systems. The systems of the Unified Science Center are entirely CFC-free, using primarily R-123, and therefore satisfying the requirements of this prerequisite.

Credit 1: Optimize Energy Performance — **Unknown**

The requirements for these credits are similar to those of Prerequisite 2; again, information pertaining to energy models was unavailable for this report, but it may be assumed that the Unified Science Center will obtain some credits related to this section.

Credit 2: On-site Renewable Energy **No**

This credit provides incentive to produce renewable energy on-site to reduce emissions from fossil fuel energy use. The Unified Science Center is not designed to generate any energy on site, and is not eligible for this credit.

Credit 3: Enhanced Commissioning **Unknown**

Credit 3 offers two points for enhanced commissioning involving a third party prior to the start of the construction document phase. At the time of this report, information about such commissioning was not available.

Credit 5: Measurement and Verification **Yes**

This credit provides for the ongoing accountability of building energy consumption over time. The Unified Science Center is specified to undergo a process of measurement and verification, and is therefore eligible for these 3 credits.

Credit 6: Green Power **Unknown**

This credit requires the purchase of a green power generation contract; it is unknown whether the Unified Science Center will qualify for these credits.

Indoor Environmental Quality

Prerequisite 1: Minimum Indoor Air Quality Performance **Yes**

This prerequisite requires the ventilation system to adhere to the requirements of the ventilation rate procedure of ASHRAE Standard 62.1. In Technical Report 1, it was concluded that the Unified Science Center meets these requirements, and meets this prerequisite.

Prerequisite 2: Environmental Tobacco Smoke Control **Yes**

The Unified Science Center is a non-smoking facility with air intakes at the roof level, and therefore meets the requirements of this prerequisite.

Credit 1: Outdoor Air Delivery Monitoring **No**

To achieve this credit, CO_2 monitoring must be specified for all densely occupied spaces. Though CO_2 monitors are in place in the Unified Science Center, they are not widespread enough to achieve the point offered by this credit.

Credit 2: Increased Ventilation **Yes**

This credit requires additional outdoor air ventilation to improve indoor air quality; with 100% outside air delivered to the majority of the building at all times, the Unified Science Center qualifies for this credit.

Credit 7: Thermal Comfort **Yes**

This credit requires HVAC systems to provide an indoor environment that adheres to the conditions of ASHRAE Standard 55. As evidenced by Table 2, the Unified Science Center is well within the range established by this standard, and therefore qualifies for this credit.

DESIGN HEATING AND COOLING LOADS

In Technical Report 2 – *Building and Plant Energy Analysis*, heating and cooling loads were simulated using Trane TRACE. Table 11 shows the estimates produced by the software. The modeled values are generally similar to those in the design documents, with the notable exception of the supply air rate for AHU 5. Difficulty in accurately modeling the complexities of the system likely accounts for this discrepancy; subsequent attempts to improve the model have not yielded significantly better results.

Table 11: Heating and Cooling Loads

	Cooling Load (ft^2/ton)	Heating Load (BTUh/ft^2)	Supply Air (CFM/ft^t)		
			AHUs 1&2	**AHUs 3&4**	**AHU 5**
Designed	180	70	1.14	1.17	1.54
Modeled	168	64	1.21	1.32	4.5

To evaluate the financial impact of these loads, utility rates were estimated based on average values for Northeastern Pennsylvania, and can be found in Table 12. Though electricity rates fluctuate yearly, they average at about $0.10/kWh, which was the value used for estimation. Current natural gas rates are likely to decrease in the future as a result of developments in local Marcellus shale mining, but a conservative rate was used in analysis nonetheless.

Table 12: Utility Rates

Gas and Electricity Rates	
Electricity Demand	$10.00/kW
Electricity Supply	$0.10/kWh
Gas	$0.72/therm
Water	$11.00/1000 gallons

ANNUAL ENERGY CONSUMPTION AND COSTS

In Technical Report 2 – *Building and Plant Energy Analysis*, annual energy use was simulated using Trane TRACE. Table 13 shows the estimates produced by the software. Analysis shows that natural gas, used for hot water heating, is the largest load for this building. This large load is due the building's location and the demand required by the 100% outside air AHUs.

Table 13: Annual Energy Consumption

Annual Energy Consumption				
Load	**Electricity (kWh)**	**Natural Gas (kBTU)**	**Water (1,000 gal)**	**% of Total**
Heating				**80**
Primary		**21,234,448**		**79.5**
Other	**127,024**			**0.6**
Cooling				**6**
Compressor	**1,615,573**			**3.6**
Cooling Tower/ Condenser Fans	**398,595**		**16,550**	**0.9**
Condenser Pump	**220,635**			**0.5**
Auxiliary				**9**
Supply Fans	**3,489,151**			**7.7**
Pumps	**569,932**			**1.3**
Other				**5**
Lighting	**1,425,080**			**3.2**
Receptacles	**820,778**			**1.8**
Totals	**8,666,768**	**124,195,200**	**16,550**	**100**

Monthly Energy Consumption

Figures 9 and 10 show the fluctuations in energy usage over the course of the design year. As expected for this climate, electricity use peaks in the summer months (Fig. 9), while gas usage peaks in the winter (Fig. 10). Figure 10 also indicates a summertime surge in natural gas consumption, the reason for the unexpectedly large annual heating load seen in Table 13. This spike is most likely due to the modeled interior and underground spaces requiring VAV reheat during the summer, and is most likely not a realistic estimate of this building's gas consumption. Table 14 shows the numerical values which were given by TRACE and used to produce these graphs.

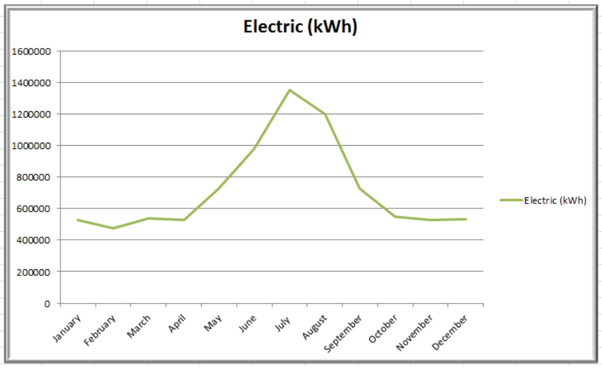


Fig. 9: Monthly Electricity Consumption

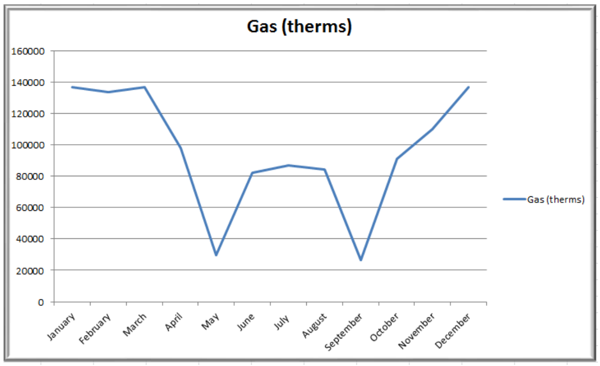


Fig. 10: Monthly Natural Gas Consumption

Table 14: Monthly Energy Consumption

Monthly Energy Consumption												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Electric - on peak (kWh)	196594	176785	217748	194321	342564	490203	483988	537002	333919	213753	204135	187979
Electric - off peak (kWh)	332773	299699	320868	334547	383614	486969	867202	663076	395704	336323	324621	342380
Electric - total (kWh)	529367	476484	538616	528868	726178	977172	1351190	1200078	729623	550076	528756	530359
Gas (therms)	136759	133524	136759	97817	29510	82032	86759	84266	26468	91261	110038	136759

Annual Energy Cost Analysis

Table 15: Monthly Energy Costs

Monthly Energy Costs					
Month	**Electricity ($)**	**Natural Gas ($)**	**Water ($)**	**Total ($)**	**% of Annual Total**
January	28,464	98,467	9,485	136,415	8.5
February	26,422	88,938	8,510	123,869	8
March	30,769	98,467	9,862	139,098	9.6
April	28,516	70,428	10,001	108,945	6.6
May	55,419	21,247	15,190	91,857	6
June	71,003	66,263	22,573	159,839	10
July	71,142	98,467	32,532	202,141	12.5
August	76,423	89,472	28,723	194,618	12
September	55,737	19,057	15,350	90,143	5.5
October	31,561	65,708	10,450	107,719	6.5
November	30,023	30,023	9,805	119,055	7.4
December	27,748	27,748	9,570	135,785	8.4
Totals	**533,228**	**894,205**	**182,051**	**1,609,484**	**100**

Table 15 provides a monthly summary of overall utility costs based on the rates in Table 12. Figure 11 provides a graphical representation of overall monthly utility costs. Energy costs will be at their peak in the summer months as a result of the cooling demand; an increase in natural gas consumption also contributes to this peak in overall energy costs. Natural gas usage constitutes the greatest economic cost, at 55% of the yearly total.

The building will cost approximately $8.04/ft^2 to operate for a typical year. Comparisons of the costs according to type can be found in Figure 12 and Table 16.

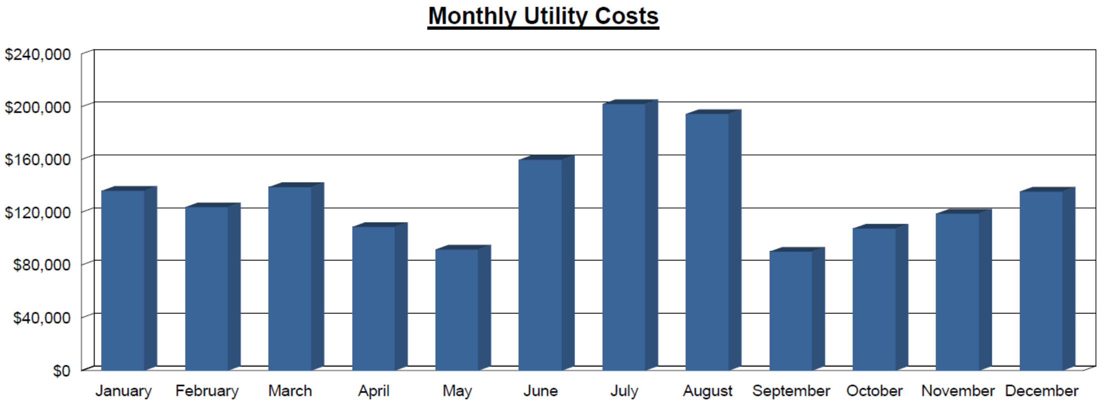


Fig. 11: Monthly Utility Costs

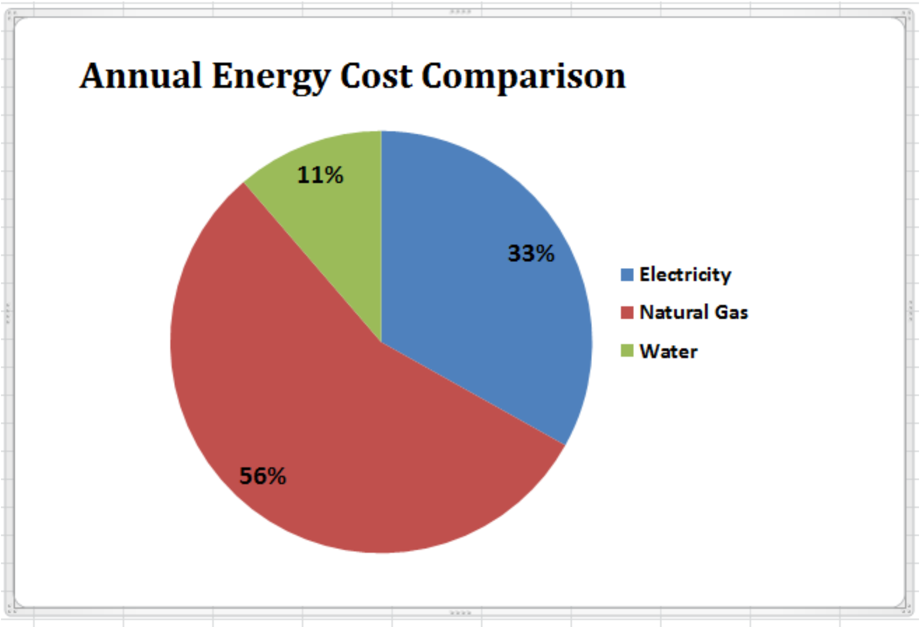


Fig. 12: Annual Energy Cost Comparison

Table 16: Utility Cost Comparison

Overall Cost Comparison			
Electricity	Natural Gas	Water	Overall
$2.66/ft^2$	$4.47/ ft^2$	$0.91/ ft^2$	$8.04/ ft^2$

Annual Energy Emissions

An emissions calculation was performed using the results of TRACE analysis and the 2007 NREL Regional Grid Emission Factors data. This project is located in the Eastern Interconnection of the North American Electrical Reliability Council electrical grid depicted in Figure 13.

Analysis shows that emissions are primarily the result of delivered electricity. This is the result of the large building electrical loads in combination with the poor efficiency of delivering the electricity itself. High efficiency on-site low-No_x boilers with sealed combustion effectively limit environmental impact from natural gas combustion. The TRACE model produced the summary of overall annual emissions found in Table 17.

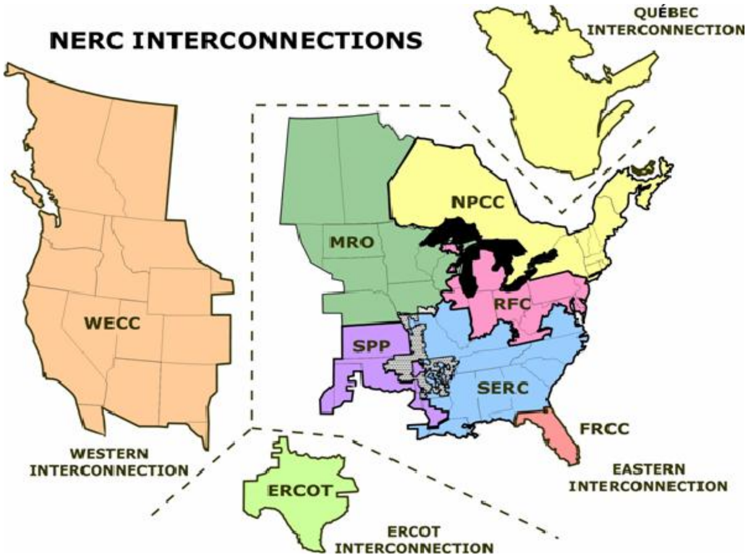


Fig. 13: NERC Electrical Grids

Table 17: Emissions Summary

Computed Emissions Summary		
CO_2	SO_2	NO_x
54,797,620 lb/yr	423,662 gm/yr	85,156 gm/yr

Tables 18 and 19 summarize emissions from delivered electricity and on-site combustion, respectively.

Table 18: Emissions from Delivered Electricity

Annual Emissions from Delivered Electricity		
Pollutant	lb of Pollutant per kWh of Electricity	Annual lb of Pollutant
		Annual Electricity Consumption = 8,666,768 kWh
CO2e	1.74E+00	15080174.58
CO2	1.64E+00	14213497.88
CH4	3.59E-03	31113.69
N2O	3.87E-05	335.40
NOX	3.00E-03	26000.30
SOX	8.57E-03	74274.19
CO	8.54E-04	7401.42
TNMOC	7.26E-05	629.21
Lead	1.39E-07	1.20
Mercury	3.36E-08	0.29
PM10	9.26E-05	802.54
Solid Waste	2.05E-01	1776687.24
Total Annual Emissions (lb)		31,210,917.95

Table 19: Emissions from Natural Gas Consumption

Annual Emissions from Natural Gas Boilers		
Pollutant	lb of Pollutant per 1000 ft3 Natural Gas	Annual lb of Pollutant
CO2e	1.23E+02	141690.096
CO2	1.22E+02	140538.144
CH4	2.50E-03	2.87988
N2O	2.50E-03	2.87988
NOX	1.11E-01	127.866672
SOX	6.32E-04	0.728033664
CO	9.33E-02	107.4771216
VOC	6.13E-03	7.06146576
Lead	5.00E-07	0.000575976
Mercury	2.60E-07	0.000299508
PM10	8.40E-03	9.6763968
Total Annual Emissions (lb)		282,486.8103

EVALUATION OF SYSTEMS AS DESIGNED

In general, the mechanical systems of the Unified Science Center are well thought out and expertly designed to achieve the goals set forth by the owners. Potential safety risks involving recirculation of contaminants from laboratory spaces have been entirely avoided by using 100% outside air handling units, though this design choice has in turn magnified heating fuel consumption and costs.

The layout of the mechanical systems and duct shafts is nicely integrated with the architecture of the building, providing efficiency in construction and maintenance. In addition, the equipment used in the design boasts high efficiency, offsetting the costs incurred by the air handling units. Overall, the mechanical systems of the Unified Science Center comply with relevant ASHRAE Standards and are designed to push the building toward LEED Silver Certification.

Great care was taken in the design process to provide mechanical, electrical, and plumbing systems that are appropriate for this project. The factors that most heavily influenced design were occupant safety and energy efficiency, so any alternatives to be considered must meet these criteria at a minimum.

PART 2: ALTERNATE SYSTEMS STUDIES

PROPOSED ALTERNATE SYSTEMS

While the mechanical systems are well designed to meet the requirements of relevant ASHRAE Standards and LEED Certification, there are several alternatives that may further reduce purchased energy consumption and operating costs. The primary objective of proposed alternatives is to reduce the Unified Science Center's carbon footprint while satisfying the criteria established by the owners. In addition, it will be useful to analyze the use of a more typical HVAC system in this building to identify the advantages of the current design over a standard approach to ventilation, temperature, and humidity control. The alternatives discussed in this report include heat recovery wheels and chilled beams to improve energy efficiency, as well as analysis of the potential use of Variable Air Volume air handling units to provide a reference for the performance of the current design.

Heat Recovery Wheels

Each of the AHUs is currently equipped with a total energy recovery (enthalpy) wheel, which transfers both latent and sensible heat between the exhaust and supply airstreams. While this is an effective method to provide supply air at a reasonable temperature, it is easily augmented through the addition of a heat recovery wheel that transfers only sensible heat. Based on comparisons of the simulated performance of each configuration, the dual-wheel configuration outperforms a single enthalpy wheel in terms of heating energy use by eliminating the need for a heating coil downstream of the wheel, and significantly reducing the need for space reheat. Figure 14, from Dr. Stanley Mumma's ASHRAE Journal article *Designing Dedicated Outdoor Air Systems*, illustrates the differences between these two configurations:

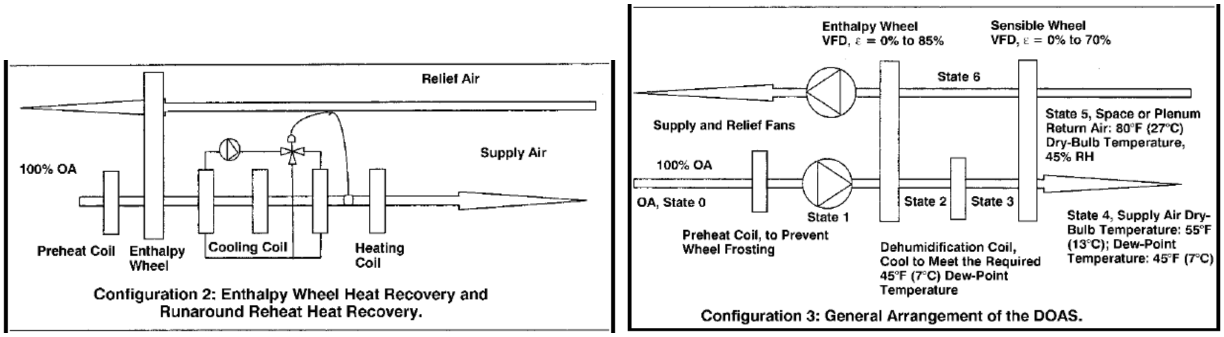


Figure 14: Single vs. Dual Wheel DOAS Configurations

Chilled Beams

Active chilled beams have been in use for many years in Europe, but only recently have they been considered a feasible alternative to conventional HVAC systems in the United States. While air diffusion is currently achieved through the use of fan coil units, VAV boxes, and CV boxes, the use of active chilled beams has the potential to further reduce the energy required to provide local cooling, and would also significantly reduce construction cost and floor-to-floor height as well as the required size of the AHUs, chillers, boilers, and ducting.

The greatest drawback to the use of chilled beam systems is the possibility of condensation, which results from uncontrolled humidity in the space. However, this can be avoided with appropriate sizing and ventilation air. In some laboratory spaces, the use of chilled beams prompts high safety airflow rates because of fume hood exhaust rates, and distinct airflow patterns require chilled beams to be configured properly to prevent the possibility of contamination. Fortunately, the majority of the laboratory spaces in the Unified Science Center do not have a high density of fume hoods, though many labs in the new construction have large areas of fenestration which may present difficulties with condensation. Even so, these and a large number of labs and classroom spaces being renovated as part of this project stand to benefit from the use of chilled beams for space conditioning.

Variable Air Volume AHUs

Since the current design of the Unified Science Center incorporates cutting edge technology in its mechanical equipment and controls, it has been shown in the first three technical reports that this building's indoor air quality and energy performance exceeds that of more traditional approaches to HVAC systems for buildings of this type. However, it would be helpful to establish a definition of a "traditional approach" and implement it in this project to provide a reference for the mechanical systems as designed. For the purposes of education, this approach would be valuable to understand the advantages a Dedicated Outdoor Air System offers over a standard solution for these types of spaces.

A traditional approach would be a VAV supply air system with VAV terminal reheat. According to Philip Bartholomew's article *Makeup Air Heat Recovery: Saving Energy in Labs*, these standard VAV systems waste large amounts of both refrigeration and heat input energy. By analyzing this type of system in the Unified Science Center, it will be possible to identify the ways in which this energy is wasted and in what ways the current design outperforms it.

BREADTH STUDIES

The focus of breadth studies proposed in this report is to complement the study of mechanical systems by investigating the impact of other building systems on the HVAC requirements. In addition, sustainability plays a large role in the design of this building, and it would be advantageous to identify additional methods to reduce this building's carbon footprint and accumulate LEED points for future certification. This will require a broad study of sustainable architecture applications and an examination of the Unified Science Center's electrical system.

Architecture/Sustainability

Though the architecture of the Unified Science Center is already expertly designed to achieve energy efficiency and a comfortable aesthetic, it would be valuable to explore other architectural options that would both complement the current design and improve energy performance. For example, much of the building's fenestration is designed to be shaded with horizontal louvers; light shelves or other shading devices might provide a better-performing alternative to provide daylighting and minimize solar heat gain. This feature, however, would undoubtedly alter the overall appearance of both the façade and the inside spaces, so great care must be taken to assess the aesthetic impact of the addition of light shelves.

Large copper panels crown the building to hide mechanical systems; given the significant south- and west- facing areas of these panels, it would be worthwhile to investigate the feasibility of replacing this architectural element with solar panels to provide not only on-site energy generation, but also a strong aesthetic statement about the energy performance of the building. Other sustainable efforts such as rainwater collection may also prove to be simple and effective means of energy conservation; as in the case of the light shelves, the aesthetic impact of these methods must be considered in the analysis.

Electrical

Like its mechanical systems, the electrical systems of the Unified Science Center are designed primarily for energy efficiency. Since any redesign of mechanical systems will have an effect on electrical consumption, it is proposed that the electrical load of each mechanical alternative be compared with that of the current design to provide a more complete picture of each redesign's ultimate impact.

It will also be helpful to evaluate the effects on the electrical system of the proposed architecture studies. In particular, the use of solar panels will require a close look at their integration with the building electrical system. Since light sensors are used to adjust artificial lighting levels in many spaces, changes in shading and daylighting methods may have a significant effect on the building's overall electrical energy use.

PROJECT METHODS

In order to provide an accurate analysis of the design and proposed redesigns of the Unified Science Center, it is necessary to use a variety of software tools. To determine monthly and annual energy use and associated costs and emissions, Trane TRACE was the primary tool for load calculations. To model the building for use in building simulation programs, Autodesk REVIT acted as the workhorse, and AutoCAD was also used for the production of schematics.

To effectively understand the impact of alternate systems considered in this report, it is important to establish guidelines to determine the value of each system. The following criteria will be used to analyze the performance of alternate systems:

Initial Cost

Initial cost can often be a determining factor in the selection of HVAC systems and equipment. In many cases, systems that provide lower operating costs also result in a greater initial cost. As a state-of-the-art university science building, the Unified Science Center may be expected to be occupied for more than 50 years; over this period of time it is likely that higher initial costs will be offset by lowered operating costs. Accordingly, initial cost will not be considered as critical to system selection as other factors, but will be important to establish the payback period for each alternate system.

Operating Cost

Operating cost represents the yearly cost of utilities combined with the maintenance costs for each system. This will provide the most accurate picture of each system's performance, and with initial cost values will establish payback periods.

Environmental Impact

The impact of each system on the environment will be established by examining the energy use of each system considered in analysis. This will be an important factor to evaluate alternate systems, considering that the Unified Science Center is to be a LEED-certified building.

DEPTH STUDIES

The purpose of the depth studies included in this report is to identify ways to improve the performance of the mechanical systems in the Unified Science Center and, in the case of the VAV system study, to establish a baseline against which to compare the performance of the current system.

The system as designed performs well and satisfies the criteria set forth by the owner; however, alternatives may prove to be more cost effective in the long run with regards to energy consumption and operating costs. It should be noted that while great care was taken to model the performance of the existing system and each alternate system, no modeling effort can be assumed to be 100% accurate with regards to real-world performance; the results contained in this report represent the best estimate given the time constraints and resources at hand.

Heat Recovery Wheels

The use of dedicated outdoor air systems (DOAS) for building ventilation is a relatively recent development; as such, there are a number of configurations which can be used to heat, cool, and humidify outdoor air. The Unified Science Center is designed with AHUs which utilize enthalpy wheels to provide primary heating and cooling. However, the enthalpy wheels alone are not always sufficient to provide supply air at the proper temperature, and require heating and cooling coils downstream of the wheel to make up the difference, as shown in Figure 15. These coils accordingly necessitate hot and cold water to be provided at the expense of the energy required by the heating and cooling plants; this energy need not be expended with the use of sensible wheels in conjunction with the enthalpy wheels.

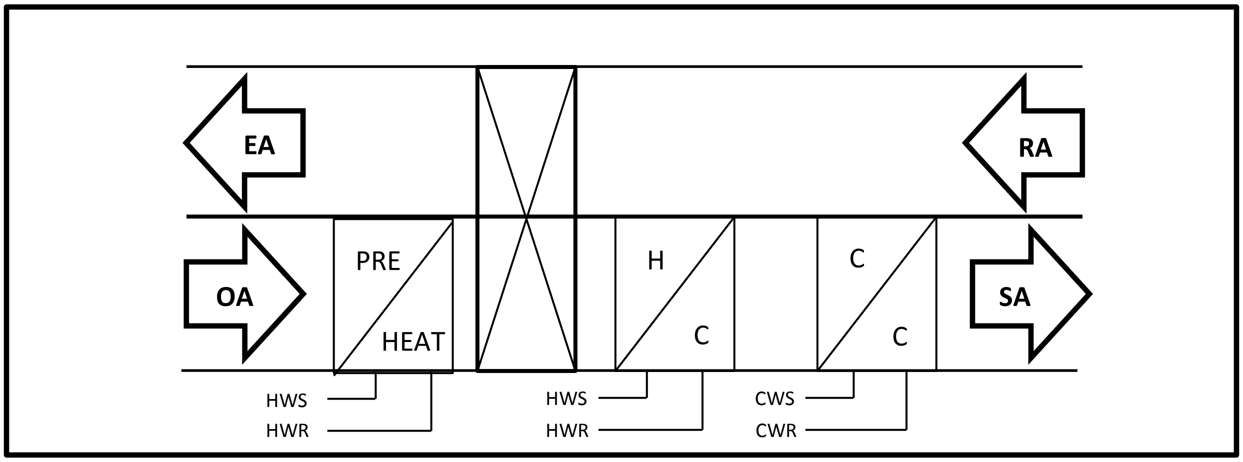


Fig. 15: DOAS System with Enthalpy Wheel Alone

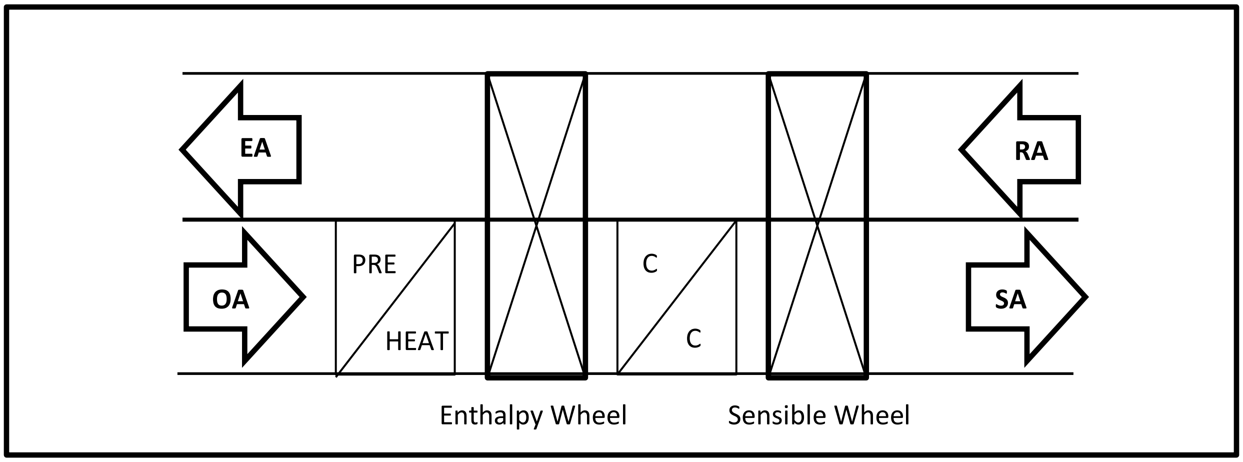


Fig. 16: DOAS System with Enthalpy Wheel and Sensible Wheel

With the dual-wheel configuration shown in Figure 16, the sensible wheel can provide additional heating and cooling in the winter and summer months respectively, and eliminate the need for the heating coil in the previous configuration. This configuration can substantially reduce the required heating hot water for the HVAC systems, and subsequently lead to a downsizing of the heating plant. Additionally, implementation of the dual-wheel configuration would not require a major redesign with respect to duct sizes, since supply air rates remain the same.

While the addition of a sensible wheel stands to greatly reduce heating costs, there are other economic considerations to take into account. Each additional wheel will require a motor at additional first cost to the owner; also, the pressure drop associated with the additional wheel must be overcome, using more fan energy.

To analyze the effects of this design, an energy model was constructed using Trane TRACE 700. For this model, all other variables of design were kept the same as in the original design, the intent of this analysis being to identify simply how the addition of a sensible wheel to each existing AHU could affect energy use.

The current design utilizes Thermotech enthalpy wheels. The redesign was completed assuming that Thermotech sensible wheels would also be used. Based on literature from Thermotech, these heat recovery wheels have an efficiency of approximately 72% at the face velocities experienced by the current enthalpy wheels; this figure was used for the TRACE analysis.

As expected, the addition of sensible wheels to each of the air handling units significantly reduces the need for heating and cooling energy. Table 20 summarizes the analysis:

Table 20: Comparison of Current Design with Redesign

	Cooling Required (Tons)	Reheat Energy Required (MBTUh)
Without Sensible Wheel	**168**	**12,800**
With Sensible Wheel	**122**	**7,400**
Reduction	**27%**	**42%**

As this table shows, adding the sensible wheel greatly reduces the energy required to provide thermal comfort to building occupants. It is interesting that the reheat energy required is reduced much more drastically than the cooling energy. This is a result of the principles upon which the wheel operates; sensible wheels transfer the greatest amount of energy when there is a large temperature difference between the two airstreams. Since northeastern Pennsylvania experiences long, harsh winters, return air at 70 – 75 degrees provides a significant amount of heat to be transferred to the supply airstream. On the other hand, summers are not very extreme in this climate, so there is less opportunity for energy transfer beneficial to cooling over the course of a year.

To assess the economic viability of this redesign, it was necessary to establish both first cost and annual energy savings in order to determine the simple payback period. According to various manufacturers, sensible wheels typically cost approximately $2/cfm. Using this figure, it was determined that adding sensible wheels would increase the first cost of the HVAC systems by at least $400,000. This is a significant sum, requiring a close look at the savings achieved by this system.

Taking into account both electricity used to provide cooling and natural gas to provide heating, savings achieved by the addition of sensible wheels to the HVAC systems total approximately $45,000 annually. These savings result in a simple payback period of about 9 years, an acceptable amount of time for a building that will likely remain occupied for several decades.

It is important to note that this simple payback period does not take into account other factors that would increase the initial cost, including potentially the cost of larger fans to overcome pressure drop and the additional construction costs associated with the installation of this equipment. Nonetheless, these costs are minimal when considered over the life cycle of the system, and sensible wheels may be considered a worthwhile investment.

Chilled Beams

Chilled beams operate by using the natural buoyancy of air at different temperatures to effectively circulate air in a space to allow warmer water temperatures to provide the same cooling effect as a conventional VAV unit. Figure 17 shows the two types of chilled beams: passive and active. Passive chilled beams operate solely on the principles of convection, and require ventilation air to be delivered by a separate air handling system; active chilled beams incorporate ventilation air into their design, and in doing so can significantly reduce fan use. Additionally, active beams have the advantage of being useful in the heating season as well; passive chilled beams are limited by their fundamental operation, which prohibits them from effectively heating spaces. Figure 18 shows the operation of active chilled beams in heating mode.

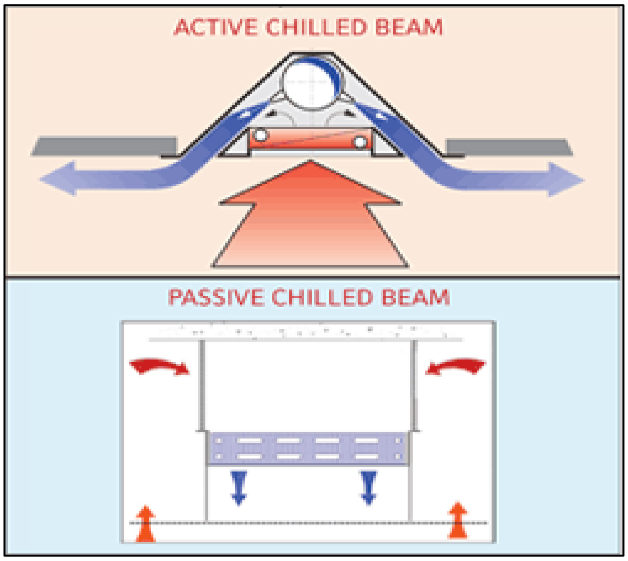


Fig. 17: Active and Passive Chilled Beam Operation

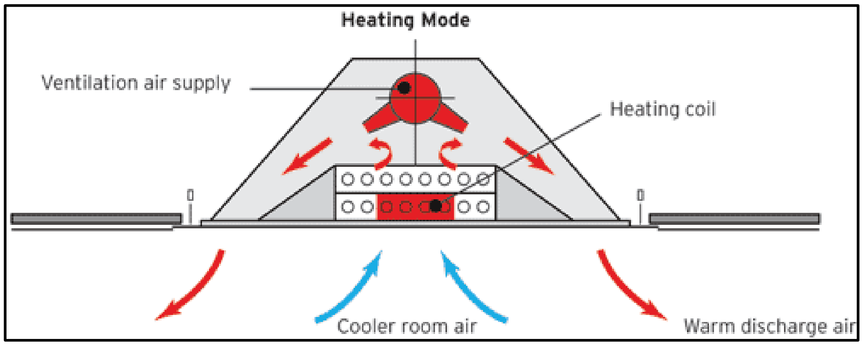


Fig. 18: Active Chilled Beam Operation in Heating Mode

Chilled beams have the added benefit of requiring far less plenum space. In some cases, this can lead to a dramatic reduction in floor-to-floor height, and associated reductions of construction materials and costs. In the case of the Unified Science Center, however, the reduction of plenum space would likely result in higher ceiling heights instead; the new construction's connection with an existing campus building is precise, and a shift in floor-to-floor heights would seriously disrupt both the interior and exterior architecture of the building. Figure 19 shows how dramatic the change in ceiling height could be for occupants.

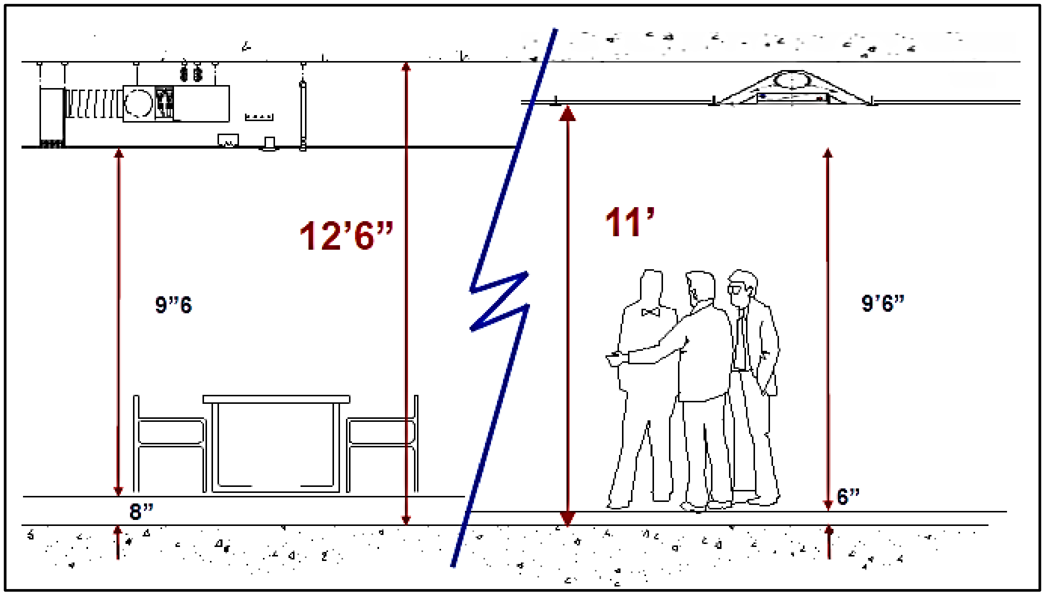
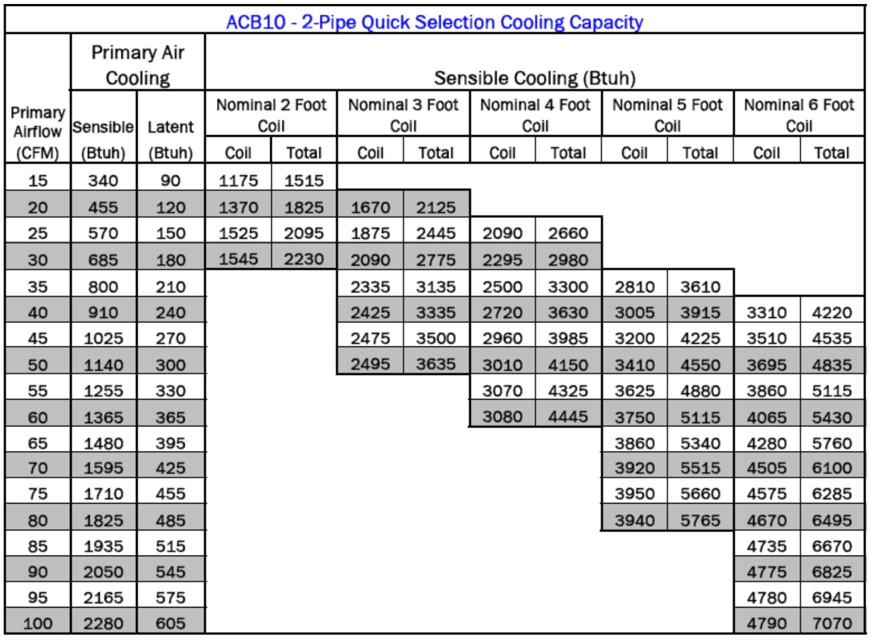


Fig. 19: Reduced Plenum Height Allowed by Chilled Beams

Because of their integration with the air distribution system and overall better performance, active chilled beams were chosen over passive beams for analysis in this report. Since chilled beams operate most effectively when used in conjunction with a dedicated outdoor air system, they are a good candidate to replace the current air distribution techniques employed in the Unified Science Center, which consist primarily of VAV terminal boxes and fan coil units. To begin, ASHRAE Standard 62.1 was employed to determine the minimum ventilation rates required for each space in the building. The results of this analysis can be found in Appendix B.

The next step was to select chilled beams from manufacturer data that would appropriately meet the sensible load and outdoor air requirements for each space. With outdoor air requirements determined via the ventilation rate procedure, sensible loads were determined using the results of a TRACE analysis. Because of their reputation in the industry and selection of products, Dadanco chilled beams were used as the basis for this analysis.

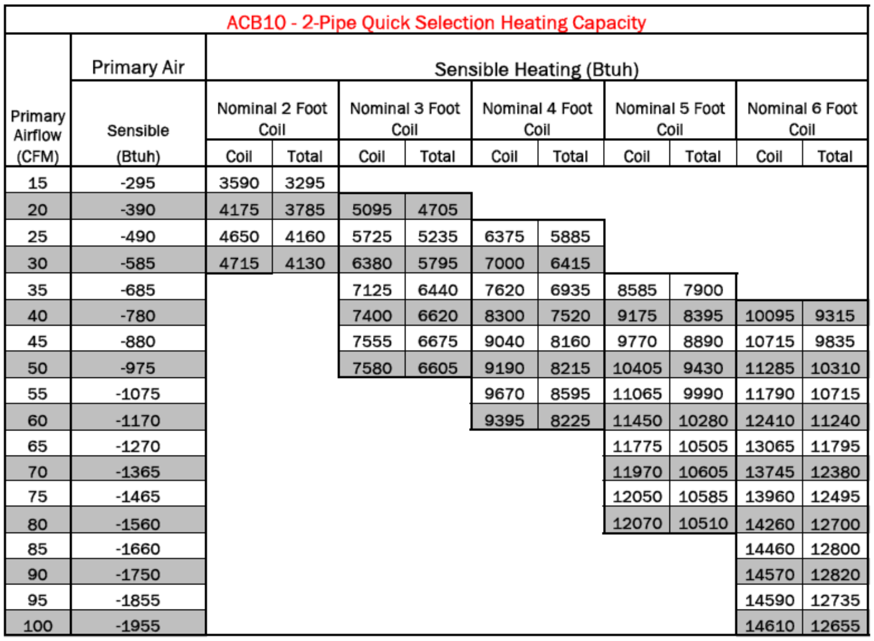
Figure 20 shows the selection chart provided by the manufacturer based on cooling capacity; these figures are based on a room design temperature of 75˚ F and water flow rate of 1.6 GPM.



ACB10 - 2-Pipe Quick Selection Cooling Capacity												
	Primary Air Cooling		Sensible Cooling (Btuh)									
			Nominal 2 Foot Coil		Nominal 3 Foot Coil		Nominal 4 Foot Coil		Nominal 5 Foot Coil		Nominal 6 Foot Coil	
Primary Airflow (CFM)	Sensible (Btuh)	Latent (Btuh)	Coil	Total	Coil	Total	Coil	Total	Coil	Total	Coil	Total
15	340	90	1175	1515								
20	455	120	1370	1825	1670	2125						
25	570	150	1525	2095	1875	2445	2090	2660				
30	685	180	1545	2230	2090	2775	2295	2980				
35	800	210			2335	3135	2500	3300	2810	3610		
40	910	240			2425	3335	2720	3630	3005	3915	3310	4220
45	1025	270			2475	3500	2960	3985	3200	4225	3510	4535
50	1140	300			2495	3635	3010	4150	3410	4550	3695	4835
55	1255	330					3070	4325	3625	4880	3860	5115
60	1365	365					3080	4445	3750	5115	4065	5430
65	1480	395							3860	5340	4280	5760
70	1595	425							3920	5515	4505	6100
75	1710	455							3950	5660	4575	6285
80	1825	485							3940	5765	4670	6495
85	1935	515									4735	6670
90	2050	545									4775	6825
95	2165	575									4780	6945
100	2280	605									4790	7070

Fig. 20: Dadanco Chilled Beam Selection Criteria – Cooling

Figure 21 shows Dadanco's heating capacity selection chart, based on a design temperature of 72˚ F; both the heating and cooling design temperatures used for these selection charts coincide with the setpoints dictated by the building designers.



ACB10 - 2-Pipe Quick Selection Heating Capacity											
	Primary Air	Sensible Heating (Btuh)									
		Nominal 2 Foot Coil		Nominal 3 Foot Coil		Nominal 4 Foot Coil		Nominal 5 Foot Coil		Nominal 6 Foot Coil	
Primary Airflow (CFM)	Sensible (Btuh)	Coil	Total	Coil	Total	Coil	Total	Coil	Total	Coil	Total
15	-295	3590	3295								
20	-390	4175	3785	5095	4705						
25	-490	4650	4160	5725	5235	6375	5885				
30	-585	4715	4130	6380	5795	7000	6415				
35	-685			7125	6440	7620	6935	8585	7900		
40	-780			7400	6620	8300	7520	9175	8395	10095	9315
45	-880			7555	6675	9040	8160	9770	8890	10715	9835
50	-975			7580	6605	9190	8215	10405	9430	11285	10310
55	-1075					9670	8595	11065	9990	11790	10715
60	-1170					9395	8225	11450	10280	12410	11240
65	-1270							11775	10505	13065	11795
70	-1365							11970	10605	13745	12380
75	-1465							12050	10585	13960	12495
80	-1560							12070	10510	14260	12700
85	-1660									14460	12800
90	-1750									14570	12820
95	-1855									14590	12735
100	-1955									14610	12655

Fig. 21: Dadanco Chilled Beam Selection Criteria – Heating

The values given by the tables in figures 20 and 21 were determined by applying the following equation:

$$q = 500 * GPM * \Delta T$$

where q represents the cooling capacity and ΔT represents the change in water temperature through the chilled beam.

2-pipe chilled beams were used for selection with the expectation that they will lower initial cost associated with piping – often a limiting factor when designers consider implementing chilled beams into building design. In examining the operating conditions of these systems, a major difference between chilled beams and conventional terminal boxes becomes apparent; Table 21 shows the difference in water temperatures for each system:

Table 21: Comparison of Current Design with Chilled Beams

Type	Entering Water Temperature (°F)
Existing Terminal Units	180
Active Chilled Beams	130

This 50 degree difference in the required water temperature to provide heating and/or reheat has a significant effect on the building heating plant. The water temperature supplied to chilled beams can be so much lower because water is used as the medium for transport of energy as opposed to air. Water can carry significantly more energy than air – a common example used to illustrate this fact is that a 1 inch diameter water pipe can carry the same amount of energy as an 18 by 18 inch air duct. As a result, boilers can run at maximum efficiencies, resulting in noticeable heating hot water cost savings.

In addition to these cost savings, further cost reduction can be realized with respect to the materials – though chilled beams often necessitate additional piping, they require only simple, inexpensive valves for operation, and with a minimum of moving parts, they need very little maintenance to remain operational.

Results of the TRACE analysis identify many ways in which the implementation of chilled beams on this project can significantly reduce annual energy consumption and costs. A summary of these results is reproduced in Table 22:

Table 22: Energy Comparison of Current Design with Chilled Beams

Energy Usage	Current Design	Chilled Beams	Reduction
Natural Gas (kBTU)	24,231,448	15, 935,939	33%
Heating Accessories (kWh)	44,633	22,622	50%
Supply Fans (kWh)	1,024,174	410,261	60%

As evidenced by the information in this table, chilled beams perform very well in terms of natural gas usage, thanks to the excellent energy transport properties of water. Chilled beams also save a staggering 60% of fan energy usage. All of these savings in energy equate to an operational cost reduction of approximately $75,000 annually.

After determining the cost savings achieved by chilled beams, the next step was to use this information to determine the payback period. This was done by identifying the total number of chilled beams that would be needed to serve the Unified Science Center based on the heating and cooling capacities determined earlier in analysis. Unit costs for the chilled beams and for the current terminal units were obtained from the manufacturer and from RS Means data, respectively. Table 23 summarizes the process of cost comparison:

Table 23: Cost Comparison of Current Design with Chilled Beams

Equipment	Cost/Unit	# of Units	Savings
VAV Terminal boxes	800	425	340,000
Fan Coil Units	1,100	48	52,800
Chilled Beams	1,000	600	-600,000

This analysis results in a net first cost of $207,200 more than that of the current design. Therefore, the simple payback period for the use of chilled beams is approximately 3 years. This payback period does not take into account the added costs associated with plumbing because pertinent information was not available; also, contractors tend to be unfamiliar with chilled beam installation, which could result in high construction cost and scheduling delays. Still, this analysis suggests that chilled beams could be implemented in the Unified Science Center with the expectation of impressive energy performance and a relatively short payback period.

Traditional VAV System

The existing HVAC system of the Unified Science Center is certainly an energy efficient design, and the additional studies included in this report identify other modern, highly efficient systems to save on energy costs over the lifetime of the building. However, it is difficult to quantify exactly how efficient these systems are without analyzing a traditional approach to heating, cooling, and ventilation. Before the advent of the technologies discussed in this report, Variable Air Volume systems served as the standard for laboratory HVAC design. Today, VAV systems are still a viable option in many buildings, but their benefits are increasingly outweighed by their drawbacks as designers become more comfortable with DOAS systems.

When compared with DOAS, VAV systems fall short on many counts. They inherently entail poor air distribution, poor humidity control, poor use of plenum space, and poor energy use. More importantly in the case of laboratory design, VAV systems do not provide easily demonstrable ventilation performance. These traditional systems, though outperformed by DOAS, have been chosen for projects nonetheless because of their relatively low initial cost. However, as DOAS is becoming increasingly popular, the initial cost of these systems can actually be equal to or lower than that of VAV systems, providing instant payback and savings.

To understand the differences between a traditional VAV system and the current DOAS design, a TRACE model was constructed using conservative parameters; adherence to ASHRAE Standard 62.1 was followed, but no heat recovery methods were utilized in this analysis in order to get a fuller sense of the importance of modern air handling technology. The results were just as expected: traditional VAV systems do not use energy efficiently, resulting in high operational costs that negate the benefits of a relatively low first cost.

Figure 22 provides a basic illustration of a typical VAV system:

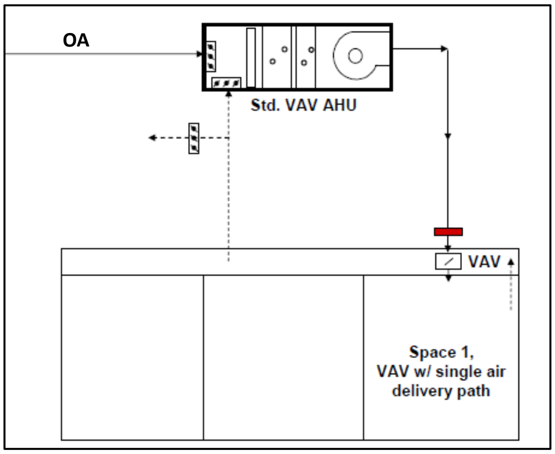


Fig. 22: Typical VAV Configuration

Table 24 shows the comparison between VAV and the existing system in terms of required CFM:

Table 24: Airflow Comparison of Current Design with VAV

System	Existing CFM	VAV CFM	Increase
AHUs 1 & 2	100,000	178,400	78%
AHUs 3 & 4	100,000	167,500	68%
AHU 5	5,150	9,200	79%

These results show the vast difference between the two systems; VAV requires much greater airflow to properly ventilate spaces in the building. This translates into larger equipment, including AHUs, ducts, chillers, and boilers.

The cooling and heating requirements shown in Table 25 further illustrate the disparity between the performance of these two systems:

Table 25: Heating and Cooling Load Comparison of Current Design with VAV

Load	Existing	VAV	Increase
Heating	64	83	30%
Cooling	168	194	16%

These increases in heating and cooling loads are, of course, coupled with associated energy consumption, costs, and emissions. A comparison of energy consumption is provided in Table 26. Altogether, the increased energy costs associated with implementation of a VAV system instead of the existing system would total approximately $200,000 per year, a figure that would quickly invalidate any first-cost savings achieved. In fact, because DOAS units perform so well and allow for decreased equipment size, it is likely that the first cost of a VAV system would not actually be significantly less. When compared with VAV systems, DOAS systems reduce the size of chillers, pumps, ductwork, plenum depth, air handling unit size, and electrical components – which all combine to make DOAS systems comparable to VAV systems in terms of initial cost. While VAV systems may be appropriate for some projects, they are certainly not cost-effective for science buildings like the Unified Science Center.

Table 26: Energy Comparison of Current Design and VAV

Annual Energy Consumption						
Load	Electricity (kWh)		Natural Gas (kBTU)		Water (1,000 gal)	
	DOAS	VAV	DOAS	VAV	DOAS	VAV
Heating						
Primary			21,234,448	28, 241, 815		
Other	127,024	156,921				
Cooling						
Compressor	1,615,573	1,874,064				
Cooling Tower/ Condenser Fans	398,595	458,384			16,550	17,442
Condenser Pump	220,635	258,142				
Auxiliary						
Supply Fans	3,489,151	4,361,438				
Pumps	569,932	683,918				
Other						
Lighting	1,425,080	1,425,080				
Receptacles	820,778	820,778				
Totals	8,666,768	10,038,725	21,234,448	28,241,815	16,550	17,442

BREADTH STUDIES

The purpose of the breadth studies included in this report is to complement the study of mechanical systems by investigating the impact of other building systems on the HVAC requirements. Since sustainability plays a large role in the design of this building, these breadth studies also aim to identify cost-effective methods of improving the energy/environmental performance and analyze their effects on the architectural aesthetics.

Light Shelves

Daylighting is the practice of allowing natural light into building spaces to reduce the need for artificial lighting sources. In addition, daylighting has been proven to improve occupant productivity – in the case of the Unified Science Center, student performance. This is a result of the direct link that is achieved to the dynamic patterns of outdoor illumination, creating a visually stimulating environment for building occupants. When fully integrated into building design, daylighting can reduce electricity use by as much as one-third, at minimal additional construction cost.

To be most effective, daylighting must be integrated into lighting controls; there is no beneficial impact on electricity use if building occupants simply turn on the lights every time they enter a room. With advanced lighting controls, it is possible to adjust the level of artificial light in a space using switching controls to turn luminaires on and off as necessary, stepping controls to turn individual lamps on and off within luminaires, and dimming controls to adjust the light output of light fixtures.

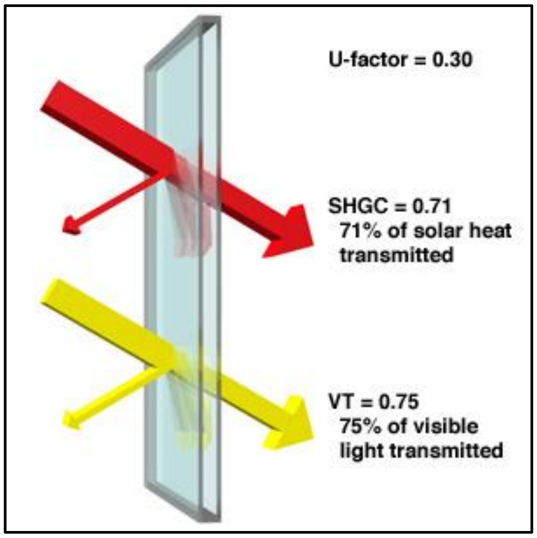


Fig. 23: Low-E Coated Glass

The Unified Science Center's design already incorporates advanced lighting controls into its design to take advantage of natural lighting; fenestration throughout the building consists of Low-E coated glass designed to reduce heat gain while admitting solar gain. Figure 23 shows the general principles of such glass. This glass is used in conjunction with horizontal sunshades to take advantage of solar geometry to allow maximum heat gain in the winter months and minimum heat gain during the summer. Figure 24 shows a schematic of the sunshades being used on the south curtain walls, while Figure 40 shows its performance.

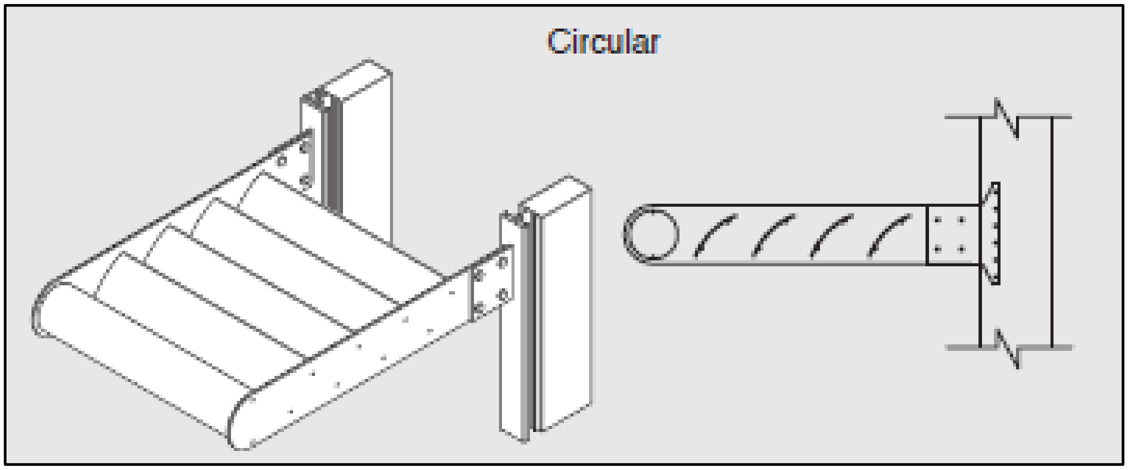


Fig. 24: Vistawall Solar Eclipse™ Circular Sunshades

As Figure 25 clearly shows, solar gain and its associated heat is allowed to penetrate deeply into the building during the winter – about 14 feet during the winter solstice. At the same time, direct solar gain is completely denied from entering the building during the summer months. This translates to lower heating and cooling loads compared to the same façade without a shading device.

Figure 25 also shows the significant plenum height designed for the Unified Science Center; the spaces that are affected by these sunshades are almost entirely laboratory spaces, which require significant ceiling space to accommodate not only HVAC and lighting equipment, but also additional ducting to vent fume hoods separately from the main air supply.

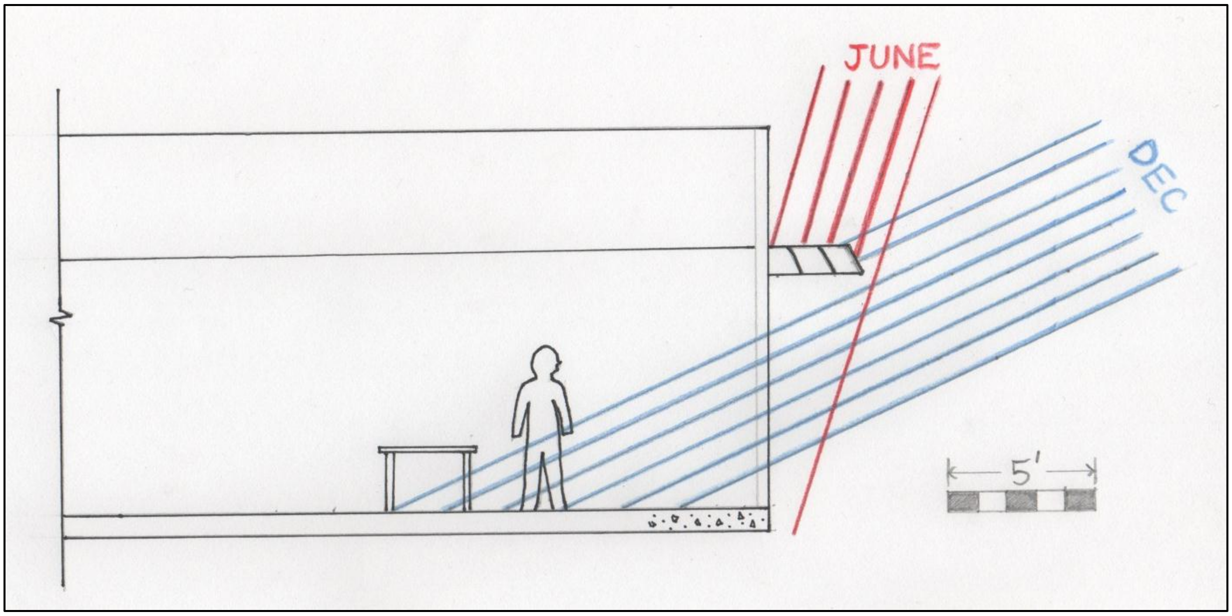


Fig. 25: Direct Solar Gain on the Summer and Winter Solstices

This large plenum space presents a significant problem when attempting to incorporate light shelves into the design, and is most likely the reason that the designers did not choose to do so. Light shelves are a very effective way of significantly increasing the natural illumination of interior spaces without bringing in too much heat gain. Figure 26 shows the general principles of light shelf design:

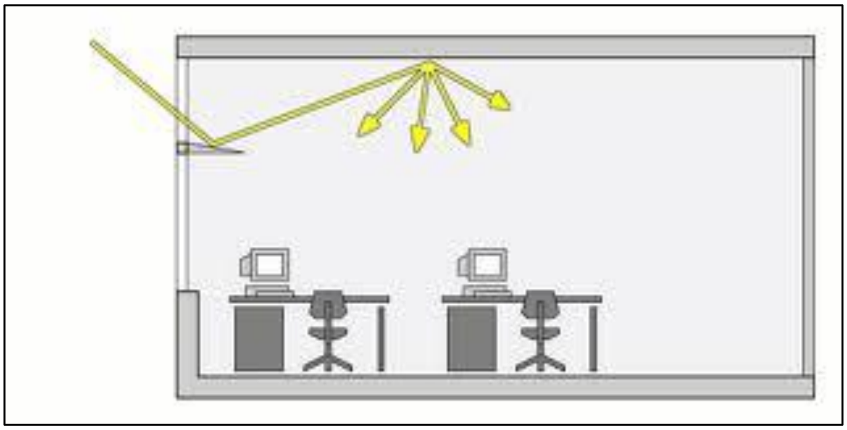


Fig. 26: Light Shelf Design

This method of daylighting, while highly effective, is subject to some significant limitations. First, for the safety of the occupants, the shelves must be positioned well above the height of a typical occupant. This in turn requires that the fenestration and the ceiling extend to a height beyond that of the light shelves in order for them to properly function. With the current design of the Unified Science Center, it would not be possible to incorporate light shelves.

However, the use of light shelves would certainly be possible if the plenum space were decreased, raising the ceiling height. In the depth study of chilled beams included earlier in this report, it was found that the use of chilled beams could significantly decrease the necessary plenum space, even with the fume hood exhaust system that will be in place in these laboratory spaces. With this in mind, further light shelf studies were conducted under the assumption that if chilled beams were in use, plenum height could be reduced by 2 feet, thus allowing the use of light shelves in the design.

Vistawall, the company that manufactures the exterior sunshades currently employed in the design of the Unified Science Center, also produces an architectural light shelf system that is meant to work in conjunction with the sunshades and seamlessly integrate into curtain wall construction in order to realize even greater energy savings. Figure 27 provides a schematic of this system:

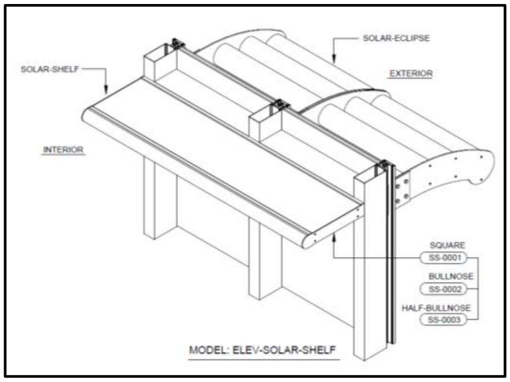


Fig. 27: Vistawall Solar Shelf™ Design

With an appropriate ceiling height, this system provides the best scenario for energy savings; the reduced heating and cooling loads realized by the exterior sunshade are maintained, and additional daylighting is provided to the space as indicated by Figure 28. Since daylight sensors are already in place in the Unified Science Center, the additional first cost would be limited to light shelf materials and labor; these costs would also be minimal, since the product comes from the same manufacturer and is made for easy field installation.

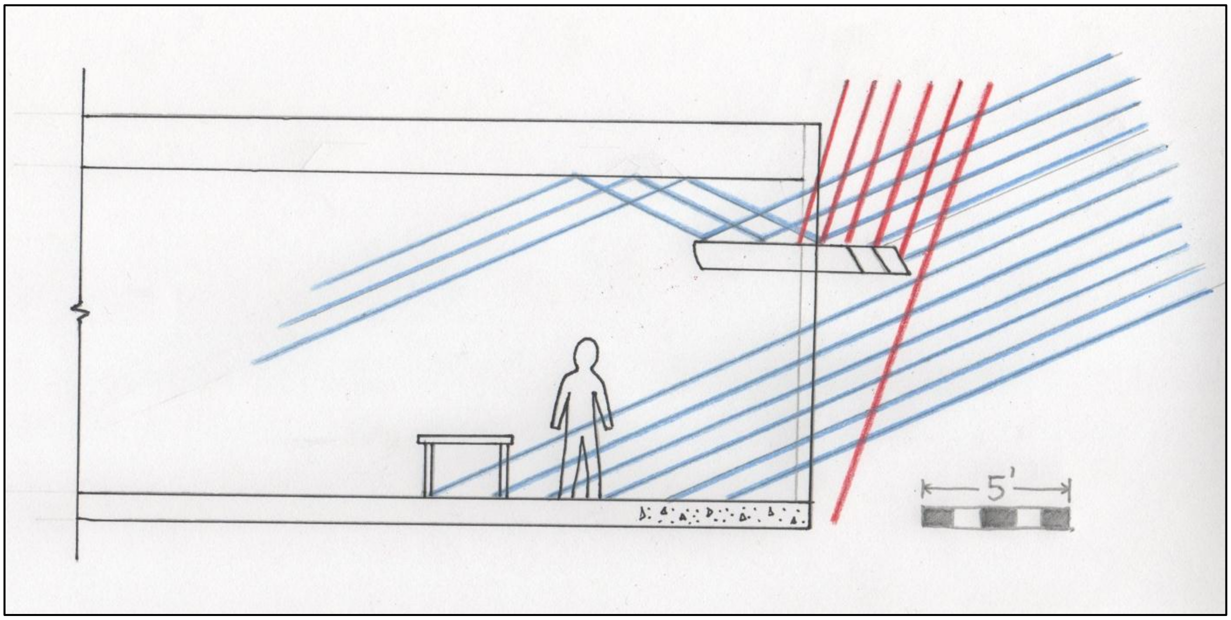


Fig. 28: Direct and Indirect Solar Gain with Light Shelf in Place

Aesthetically, the use of light shelves would have only a beneficial impact; the quality of natural light is unparalleled by the artificial light sources used in the building, and the necessary increase in ceiling height would result in a much more spacious feeling. These forces would combine to make the affected science laboratories more welcoming spaces and, ultimately, improve student performance.

Solar Panels

As the first LEED certified building on the University of Scranton campus, the owners are interested in emphasizing the energy efficiency of the building to the general public; with the entire south façade exposed to a heavily trafficked expressway, there is ample opportunity to visually express the sustainability of the building through its architecture. Figure 29 shows this south façade from a view similar to that from the highway. This rendering clearly shows the large copper panels positioned on top of the building; these panels are in place to shield the rooftop mechanical systems from public view.

Fig. 29: South Façade View from Expressway

Architecturally, these copper panels in and of themselves make a strong statement about the sustainability of the Unified Science Center; they are made of 90 to 95% recycled content and supplied by a local manufacturer. As such, they contribute to the accumulation of LEED points for the building's intended Silver certification. Aesthetically, they provide a beautiful substitute to more typical aluminum mechanical screens that often adorn buildings.

As Figure 29 illustrates, the copper panels constitute a significant surface area on the roof of this building; the amount of area which faces due south totals approximately **900 ft^2**. With such a large amount of area available, it is worth investigating the possibility of replacing these copper panels with solar panels.

Solar panels could prove to be a good replacement for the current design; they would provide a similar aesthetic impact, and might even emphasize the sustainability of the building even more, since people would immediately recognize them as a source of energy and symbol of green design. Unfortunately, photovoltaics are often dismissed as cost-prohibitive. Though a vast amount of solar energy is incident on the earth's surface, solar cells on the market today have an average efficiency of about 15%. In addition, the solar cell manufacturing industry is far from fully developed, so the cost of purchasing PV modules can adversely affect an owner's decision to employ them in building design.

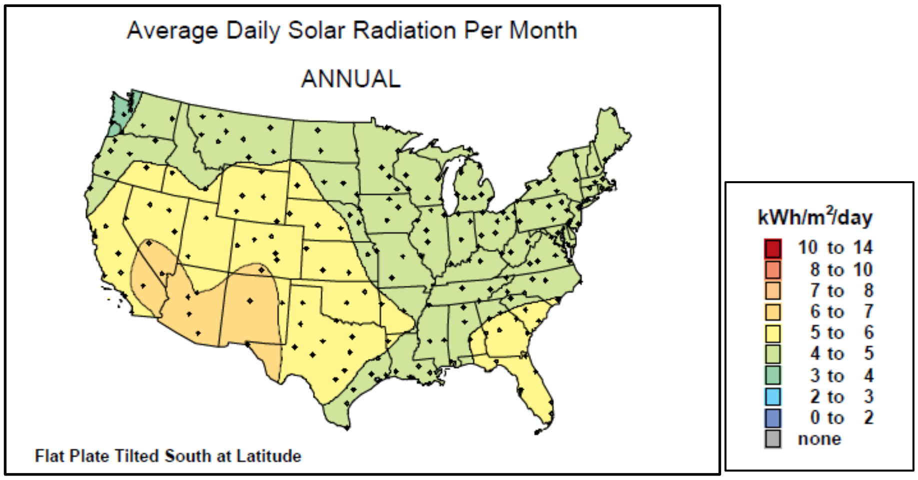


Fig 30: Average Daily Solar Radiation

The feasibility of solar panel installation is limited by the climate of the building in question. Figure 30 shows average daily solar radiation according to the National Renewable Energy Laboratory. According to the NREL, Scranton, Pennsylvania receives an average of 4 to 5 kWh/m^2/day, though these figures are a rough estimate and subject to a 30% margin of error. In addition, according to NOAA figures, Scranton only experiences about 70 clear days per year – a critical measure of solar radiation when considering the installation of solar panels.

To assess the feasibility of this solar panel installation, it was assumed based on manufacturer's data that a solar installation for 900 ft^2 of available surface area would allow for a 10 kW solar array. Such an installation would cost an average of \$100/ft^2, resulting in a total **initial cost of about \$90,000.**

Next, the AC energy derived from a 10kW array was tabulated using NREL monthly solar radiation data and converted into monetary savings; this information is summarized in Table 27. Based on this data, a 10kW solar array would equate to about **\$1,000 in energy savings per year,** resulting in a nearly **90 year payback period.**

Table 27: Estimated 10 kW Array Value

Month	Solar Radiation (kWh/m²/day)	AC Energy (kWh)	Energy Value ($)
1	2.86	714	68.30
2	3.57	792	75.76
3	4.49	1073	102.64
4	4.75	1064	101.78
5	5.12	1136	108.67
6	5.26	1102	105.42
7	5.31	1125	107.62
8	5.14	1100	105.23
9	4.62	982	93.94
10	4.06	925	88.49
11	2.65	586	56.06
12	2.31	550	52.61
Year	**4.18**	**11150**	**1066.61**

Clearly, a 90 year payback period does not equate to an acceptable investment. There are several federal and state rebates available for solar panel investments, but even with a rebate of 50% of the installed cost, the payback period would be nearly 50 years. In addition to these considerations, solar panels are considerably heavier than the copper panels designed for the Unified Science Center and would require a significant structural redesign, further extending the already extensive payback period.

Ultimately, though a rooftop solar array would provide an immediately recognizable visual representation of this building's sustainability efforts, because of the building's climate and the high costs associated with implementation of a solar array, **it is not economically viable to implement solar panels in this project.**

Rainwater Collection

The collection and reuse of rainwater is a centuries-old technique commonly used in regions where rainfall is scarce; today it is recognized as a sustainable method of conserving utility water consumption in any climate. Rainwater harvesting is a simple and effective means to reduce utility costs, and its feasibility is largely dependent on roof area and annual precipitation. The roof of the Unified Science Center covers approximately 11,000 ft^2 of area that could be used for rainwater collection; based on this area, Table 28 shows the amount of rainwater that could be collected each year.

Table 28: Volume of Harvestable Rainwater

Month	Average Precipitation (in.)	Volume (ft^3)	Volume (gallons)
January	2.1	1925	14,438
February	2.3	2108	15,813
March	2.6	2383	17,875
April	3.0	2750	20,625
May	3.7	3392	25,438
June	4.0	3667	27,500
July	3.8	3483	26,125
August	3.3	3025	22,688
September	3.3	3025	22,688
October	2.8	2567	19,250
November	3.1	2842	21,313
December	2.5	2292	17,188
Totals	36.5	33458	250,938

The next step is to identify the cost considerations of a rainwater collection system; once collected, the rainwater must be stored in underground tanks until it is ready to be used by the occupants. Xerxes® Company tanks were considered for this report. A company representative indicated that, taking into account materials and construction costs, rainwater collection systems typically cost approximately $1.50 to $2.00 per gallon of storage, placing the total initial cost of this scenario at or around **$437,500.** With utility water costing $11/1000 gallons, this volume of rainwater collection would equate to an **annual savings of about $2,750**. All of this equates to a **payback period of 160 years**, which simply is not worth the investment.

Though rainwater collection is fundamentally simple, in reality the initial costs with relation to the utility costs make it impossible to justify implementation in this project.

Impacts on Electrical System

The electrical systems in this building are well designed to efficiently deliver power to the myriad laboratory equipment, receptacle loads, and mechanical equipment. Changes made to the mechanical systems will necessarily incur changes to the electrical loads due to differing requirements for fans, motors, and other equipment. Fortunately, the redesign of panelboards in the Unified Science Center is relatively simple, since all the panelboards which serve mechanical equipment are dedicated solely to mechanical equipment.

Table 29 shows the details for the existing panelboard which serves, among other things, the motors controlling the energy recovery wheels. This panelboard includes several spare circuits; these will be used for the additional motors that would be required to control the heat recovery wheels that were proposed in the first depth study in this report. Table 30 shows the resulting panelboard after adding these additional loads.

Table 29: Existing Panelboard Serving ERWs

Description	Load (kVA)	Circuit Breaker
EF-1B (50HP)	64	150A, 3P
EF-3B (50HP)	64	150A, 3P
ERW-1 (1HP)	1.7	15A, 3P
ERW-2 (1HP)	1.7	15A, 3P
ERW-3 (1HP)	1.7	15A, 3P
ERW-4 (1HP)	1.7	15A, 3P
ERW-5 (1HP)	1.7	15A, 3P
SPARE		
AHU-1 (60HP) RETURN FAN	64	150A, 3P
AHU-3 (60HP) RETURN FAN	64	150A, 3P
SPARE		
SPARE		
SPARE		
SPARE		
EH-1 (3) 7.3KW EACH	22	40A, 3P
EH-3 (3) 7.3KW EACH	22	40A, 3P
SPARE		
SPARE		
SPARE		
SPARE		
Total Connected to Load (kVA)	308.5	
Demand Factor	1.0	
Total Demand Load (kVA)	308.5	
Line Current (Amps)	371	

Table 30: Proposed Panelboard to Serve HRWs

Description	Load (kVA)	Circuit Breaker
EF-1B (50HP)	64	150A, 3P
EF-3B (50HP)	64	150A, 3P
ERW-1 (1HP)	1.7	15A, 3P
ERW-2 (1HP)	1.7	15A, 3P
ERW-3 (1HP)	1.7	15A, 3P
ERW-4 (1HP)	1.7	15A, 3P
ERW-5 (1HP)	1.7	15A, 3P
SPACE		
AHU-1 (60HP) RETURN FAN	64	150A, 3P
AHU-3 (60HP) RETURN FAN	64	150A, 3P
HRW-1 (1HP)	1.7	15A, 3P
HRW-2 (1HP)	1.7	15A, 3P
HRW-3 (1HP)	1.7	15A, 3P
HRW-4 (1HP)	1.7	15A, 3P
HRW-5 (1HP)	22	40A, 3P
EH-1 (3) 7.3KW EACH	22	40A, 3P
EH-3 (3) 7.3KW EACH		
SPACE		
SPACE		
SPACE		
Total Connected to Load (kVA)	317	
Demand Factor	1.0	
Total Demand Load (kVA)	317	
Line Current (Amps)	380	

As these tables clearly show, the addition of heat recovery wheels to each of the AHUs results in an increase of only 9A to this panelboard; this increase is within the ampacity limits of the currently designed wire sizes and would require no significant change to the power supply of this panelboard; this translates into minimal construction cost impact due to electrical system alterations, with connections to the motors and controls being the only necessary additions.

Due to the time constraints of this report, a detailed analysis of the electrical system impacts of the active chilled beam system and the VAV system depths could not be performed. However, a great deal of research helped produce Table 99, which summarizes the relative performance of each system with regards to the electrical system:

Table 31: Comparison of Active Chilled Beams vs. VAV

Item	VAV	ACB
Fan Energy	High	Low
Pump Energy	Low	High
Maintenance	High	Low
System Complexity	Low	High
Control System Complexity	High	Low

As this table shows, an active chilled beam system would require significantly greater pump energy to provide water to the beams, but significantly saves on fan energy; ultimately the savings associated with fan energy outweigh the added pump energy, and in terms of electrical connections, active chilled beams are likely the preferred choice over either of the other depth studies considered.

Conclusions

After analyzing all of the data produced for this report by hand calculations, load and energy simulation software, and research, it appears that the Unified Science Center is already designed to reach near maximum energy- and cost-saving potential. My expectation when beginning these analyses was that the chilled beam system would overcome its first-cost drawbacks and stand out as a contender to maximize energy savings, and with a 3-5 year payback period, it is certainly a viable option. However, the unfamiliarity with the system in the field could prove to be a significant limit to its application, and lingering concerns about condensation on the large areas of fenestration prohibit me from making a definitive recommendation for an active chilled beam system.

Heat recovery wheels seem to have the greatest potential for use with the current system of the Unified Science Center. Though they have a payback period of about 8 years, this building will certainly be in use for decades to come, and would benefit economically and environmentally from their implementation in this project, since they require very little alteration to the existing design.

I was disappointed to find that neither solar panels nor rainwater harvesting methods are realistic options; as a LEED certified project, having a solar array crown the roof would be an impressive display of the Unified Science Center's sustainability efforts. Unfortunately, they would probably need to be replaced before they even started to turn a profit for the owners.

Light shelves are a good option, considering the amount of south-facing glazing that could take advantage of solar gain. Unfortunately, the current design of the mechanical systems includes a plenum depth that prohibits their use.

PART 3: REFERENCES

Bibliography

Project documentation provided by Einhorn Yaffee Prescott Architecture & Engineering, P.C.

<http://doas.psu.edu>

US Green Building Council. LEED 2009 for New Construction and Major Renovations. Washington, D.C.: US Green Building Council, Inc., 2009.

Deru, M., and P. Torcellini. *Source Energy and Emission Factors for Energy Use in Buildings*. Oak Ridge, TN: U.S. Department of Energy, 2007.

ASHRAE, *2009 Fundamentals.*

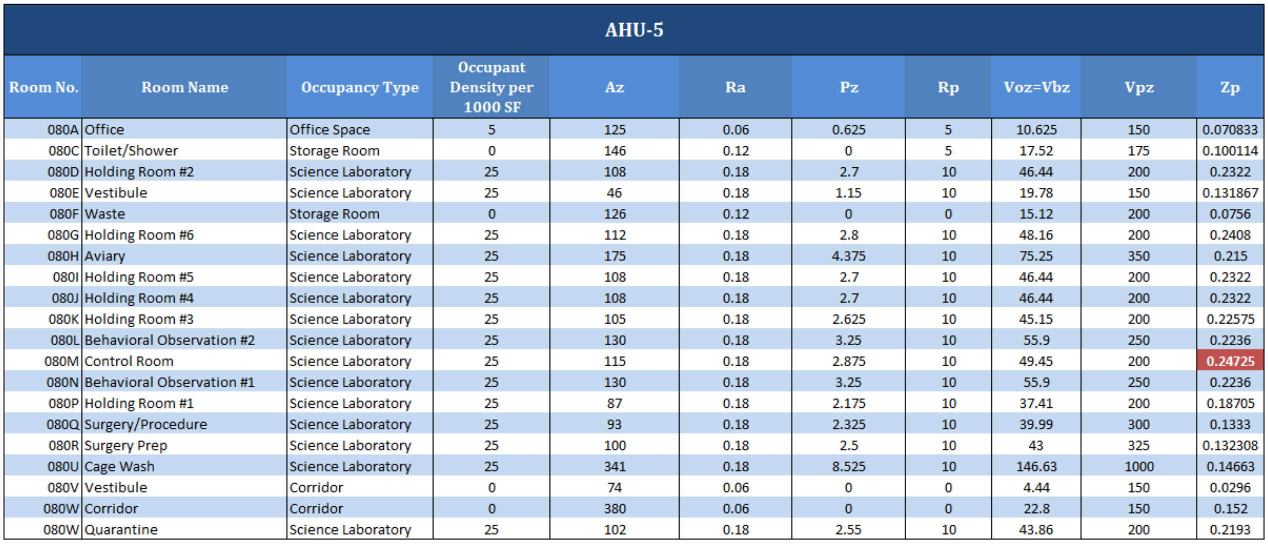
Appendix A

List of Tables

List of Figures

Appendix B

ASHRAE Standard 62.1 Section 6: Ventilation Rate Procedure



AHU-5

Room No.	Room Name	Occupancy Type	Occupant Density per 1000 SF	Az	Ra	Pz	Rp	Voz=Vbz	Vpz	Zp
080A	Office	Office Space	5	125	0.06	0.625	5	10.625	150	0.070833
080C	Toilet/Shower	Storage Room	0	146	0.12	0	5	17.52	175	0.100114
080D	Holding Room #2	Science Laboratory	25	108	0.18	2.7	10	46.44	200	0.2322
080E	Vestibule	Science Laboratory	25	46	0.18	1.15	10	19.78	150	0.131867
080F	Waste	Storage Room	0	126	0.12	0	0	15.12	200	0.0756
080G	Holding Room #6	Science Laboratory	25	112	0.18	2.8	10	48.16	200	0.2408
080H	Aviary	Science Laboratory	25	175	0.18	4.375	10	75.25	350	0.215
080I	Holding Room #5	Science Laboratory	25	108	0.18	2.7	10	46.44	200	0.2322
080J	Holding Room #4	Science Laboratory	25	108	0.18	2.7	10	46.44	200	0.2322
080K	Holding Room #3	Science Laboratory	25	105	0.18	2.625	10	45.15	200	0.22575
080L	Behavioral Observation #2	Science Laboratory	25	130	0.18	3.25	10	55.9	250	0.2236
080M	Control Room	Science Laboratory	25	115	0.18	2.875	10	49.45	200	0.24725
080N	Behavioral Observation #1	Science Laboratory	25	130	0.18	3.25	10	55.9	250	0.2236
080P	Holding Room #1	Science Laboratory	25	87	0.18	2.175	10	37.41	200	0.18705
080Q	Surgery/Procedure	Science Laboratory	25	93	0.18	2.325	10	39.99	300	0.1333
080R	Surgery Prep	Science Laboratory	25	100	0.18	2.5	10	43	325	0.132308
080U	Cage Wash	Science Laboratory	25	341	0.18	8.525	10	146.63	1000	0.14663
080V	Vestibule	Corridor	0	74	0.06	0	0	4.44	150	0.0296
080W	Corridor	Corridor	0	380	0.06	0	0	22.8	150	0.152
080W	Quarantine	Science Laboratory	25	102	0.18	2.55	10	43.86	200	0.2193

AHU-1 and AHU-2									
Room Name	**Occupancy Type**	**Occupant Density per 1000 SF**	**A_z**	**R_a**	**P_z**	**R_p**	**$V_{oz}=V_{bz}$**	**V_{pz}**	**Z_p**
16 Seat Classroom	Classroom	31	513	0.12	16	10	221.56	600	0.369266667
31 Seat Classroom	Classroom	44	705	0.12	31	10	394.6	1000	0.3946
Advanced Bio & Neuro Prep	Science Laboratories	25	607	0.18	15.175	10	261.01	630	0.414301587
Advanced Lab Prep Room	Science Laboratories	25	692	0.18	17.3	10	297.56	730	0.407616438
Advanced Lab Storage	Storage Rooms	0	266	0.12	0	0	31.92	200	0.1596
Advanced Teaching Lab	Science Laboratories	25	1107	0.18	27.675	10	476.01	7500	0.063468
Autoclave	Science Laboratories	25	148	0.18	3.7	10	63.64	500	0.12728
Autoclave	Science Laboratories	25	208	0.18	5.2	10	89.44	1400	0.063885714
Bio Hazard	Storage Rooms	0	59	0.06	0	0	3.54	0	Negatively Pressurized
BioChem/Molecular Teaching Lab	Science Laboratories	25	910	0.18	22.75	10	391.3	1250	0.31304
Break Room	Break Rooms	25	145	0.06	3.625	5	26.825	200	0.134125
Break Room	Break Rooms	25	145	0.06	3.625	5	26.825	200	0.134125
Cell Culture Room	Science Laboratories	25	212	0.18	5.3	10	91.16	350	0.260457143
Cell/Imm/Viro Teaching Lab	Science Laboratories	25	925	0.18	23.125	10	397.75	1200	0.331458333
Chem Teaching	Science Laboratories	25	645	0.18	16.125	10	277.35	1250	0.22188
Chemical Storage	Storage Rooms	0	315	0.06	0	0	18.9	300	0.063
Cleaning/Glass Wash	Break Rooms	25	145	0.06	3.625	5	26.825	100	0.26825
Cold Room	Storage Rooms	0	120	0.06	0	0	7.2	50	0.144
Corridor	Corridor	0	739	0.06	0	0	44.34	375	0.11824
Corridor	Corridor	0	561	0.06	0	0	33.66	300	0.1122
Corridor	Corridor	0	585	0.06	0	0	35.1	325	0.108
Corridor	Corridor	0	453	0.06	0	0	27.18	300	0.0906
Corridor	Corridor	0	458	0.06	0	0	27.48	325	0.084553846
Corridor	Corridor	0	420	0.06	0	0	25.2	300	0.084
Corridor	Corridor	0	417	0.06	0	0	25.02	300	0.0834
Corridor	Corridor	0	417	0.06	0	0	25.02	300	0.0834
Corridor	Corridor	0	402	0.06	0	0	24.12	350	0.068914286
Corridor	Corridor	0	323	0.06	0	0	19.38	300	0.0646
Corridor	Corridor	0	319	0.06	0	0	19.14	300	0.0638
Corridor	Corridor	0	318	0.06	0	0	19.08	300	0.0636
Corridor	Corridor	0	312	0.06	0	0	18.72	300	0.0624
Corridor	Corridor	0	323	0.06	0	0	19.38	350	0.055371429
Corridor	Corridor	0	323	0.06	0	0	19.38	350	0.055371429
Corridor	Corridor	0	318	0.06	0	0	19.08	350	0.054514286
Corridor	Corridor	0	314	0.06	0	0	18.84	350	0.053828571
Corridor	Corridor	0	312	0.06	0	0	18.72	350	0.053485714
CS Office	Office Space	5	127	0.06	0.635	5	10.795	100	0.10795
CS Print Room & Thesis Storage	Computer Lab	25	96	0.12	2.4	10	35.52	125	0.28416
CS Research Lab	Science Laboratories	25	207	0.18	5.175	10	89.01	400	0.222525
CS Server/Storage Room	Electrical Equipment	0	219	0.06	0	0	13.14	100	0.1314
Cylinder Room	College Laboratory	25	311	0.18	7.775	10	133.73	300	0.445766667
Dark Room	Photo Studios	10	85	0.12	0.85	5	14.45	50	0.289
Dark Room	Photo Studios	10	87	0.12	0.87	5	14.79	100	0.1479
Dispensing	Shipping/Receiving	0	132	0.12	0	0	15.84	525	0.030171429
Dry Specimen Storage	Storage Rooms	0	162	0.12	0	0	19.44	200	0.0972
Elec Room	Electrical Equipment	0	92	0.06	0	0	5.52	350	0.015771429
Elec Room	Electrical Equipment	0	91	0.06	0	0	5.46	350	0.0156
Elec. Room	Electrical Equipment	0	131	0.06	0	0	7.86	350	0.022457143
Electrical	Electrical Equipment	0	753	0.06	0	0	45.18	500	0.09036
Electrical Room	Electrical Equipment	0	99	0.06	0	0	5.94	350	0.016971429
Electronics Lab	Electrical Equipment	0	557	0.06	0	0	33.42	970	0.034453608

Faculty Office	Office Space	5	154	0.06	0.77	5	13.09	200	0.06545
Faculty Office	Office Space	5	154	0.06	0.77	5	13.09	200	0.06545
Faculty Office	Office Space	5	154	0.06	0.77	5	13.09	200	0.06545
Faculty Office	Office Space	5	153	0.06	0.765	5	13.005	200	0.065025
Faculty Office	Office Space	5	153	0.06	0.765	5	13.005	200	0.065025
Faculty Office	Office Space	5	153	0.06	0.765	5	13.005	200	0.065025
Faculty Office	Office Space	5	153	0.06	0.765	5	13.005	200	0.065025
Faculty Office	Office Space	5	153	0.06	0.765	5	13.005	200	0.065025
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	151	0.06	0.755	5	12.835	200	0.064175
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	150	0.06	0.75	5	12.75	200	0.06375
Faculty Office	Office Space	5	149	0.06	0.745	5	12.665	200	0.063325
Faculty Office	Office Space	5	149	0.06	0.745	5	12.665	200	0.063325
Faculty Office	Office Space	5	149	0.06	0.745	5	12.665	200	0.063325
Faculty Office	Office Space	5	149	0.06	0.745	5	12.665	200	0.063325
Faculty Office	Office Space	5	149	0.06	0.745	5	12.665	200	0.063325
Faculty Office	Office Space	5	148	0.06	0.74	5	12.58	200	0.0629
Faculty Office	Office Space	5	148	0.06	0.74	5	12.58	200	0.0629
Faculty Office	Office Space	5	148	0.06	0.74	5	12.58	200	0.0629
Faculty Office	Office Space	5	148	0.06	0.74	5	12.58	200	0.0629
Faculty Office	Office Space	5	148	0.06	0.74	5	12.58	200	0.0629
Faculty Office	Office Space	5	148	0.06	0.74	5	12.58	200	0.0629
Faculty Office	Office Space	5	148	0.06	0.74	5	12.58	200	0.0629
Faculty Office	Office Space	5	147	0.06	0.735	5	12.495	200	0.062475
Faculty Office	Office Space	5	146	0.06	0.73	5	12.41	200	0.06205

Faculty/Student Research Lab	College Laboratory	25	2025	0.18	50.625	10	870.75	2400	0.3628125
Faculty/Student Research Lab	College Laboratory	25	906	0.18	22.65	10	389.58	1095	0.355780822
Faculty/Student Research Lab	College Laboratory	25	1974	0.18	49.35	10	848.82	2400	0.353675
Faculty/Student Research Lab	College Laboratory	25	2043	0.18	51.075	10	878.49	2610	0.336586207
Faculty/Student Research Lab	College Laboratory	25	1948	0.18	48.7	10	837.64	2500	0.335056
Faculty/Student Research Lab	College Laboratory	25	871	0.18	21.775	10	374.53	1200	0.312108333
Faculty/Student Research Lab	College Laboratory	25	645	0.18	16.125	10	277.35	1000	0.27735
Faculty/Student Research Lab	College Laboratory	25	803	0.18	20.075	10	345.29	1500	0.230193333
Faculty/Student Research Lab	College Laboratory	25	2000	0.18	50	10	860	4725	0.182010582
Faculty/Student Research Lab	College Laboratory	25	1093	0.18	27.325	10	469.99	2700	0.17407037
Faculty/Student Space	Conference Room	50	495	0.06	24.75	5	153.45	400	0.383625
Faculty/Student Space	Conference Room	50	495	0.06	24.75	5	153.45	400	0.383625
Faculty/Student Space	Conference Room	50	494	0.06	24.7	5	153.14	400	0.38285
Faculty/Student Space	Conference Room	50	493	0.06	24.65	5	152.83	400	0.382075
Faculty/Student Space	Conference Room	50	491	0.06	24.55	5	152.21	400	0.380525
Faculty/Student Space	Conference Room	50	491	0.06	24.55	5	152.21	400	0.380525
Faculty/Student Space	Conference Room	50	490	0.06	24.5	5	151.9	400	0.37975
Faculty/Student Space	Conference Room	50	490	0.06	24.5	5	151.9	400	0.37975
Faculty/Student Space	Conference Room	50	484	0.06	24.2	5	150.04	400	0.3751
Faculty/Student Space	Conference Room	50	483	0.06	24.15	5	149.73	400	0.374325
Faculty/Student Space	Conference Room	50	482	0.06	24.1	5	149.42	400	0.37355
Faculty/Student Space	Conference Room	50	480	0.06	24	5	148.8	400	0.372
Family Toilet	Storage Rooms	0	58	0.12	0	0	6.96	75	0.0928
Field Suite	Office Space	5	540	0.06	2.7	5	45.9	500	0.0918
Fire Pump Room	Elevator Machine Rm	0	226	0.12	0	0	27.12	150	0.1808
Flammable	Storage Rooms	0	116	0.12	0	0	13.92	50	0.2784
Graduate Research Lab	College Laboratory	25	95	0.18	2.375	10	40.85	125	0.3268
Graduate Research Lab	College Laboratory	25	93	0.18	2.325	10	39.99	125	0.31992
Graduate Research Lab	College Laboratory	25	90	0.18	2.25	10	38.7	125	0.3096
Graduate Research Lab	College Laboratory	25	90	0.18	2.25	10	38.7	125	0.3096
Graduate Space	Office Space	5	157	0.06	0.785	5	13.345	200	0.066725
Graduate Space	Office Space	5	154	0.06	0.77	5	13.09	200	0.06545
Graduate Space	Office Space	5	144	0.06	0.72	5	12.24	200	0.0612
Graduate Space	Office Space	5	141	0.06	0.705	5	11.985	200	0.059925
Graduate Space	Office Space	5	133	0.06	0.665	5	11.305	200	0.056525
Graduate Space	Office Space	5	131	0.06	0.655	5	11.135	200	0.055675
Graduate W/Up Space	Office Space	5	141	0.06	0.705	5	11.985	200	0.059925
Graduate W/Up Space	Office Space	5	117	0.06	0.585	5	9.945	200	0.049725
Hazardous Waste	Storage Rooms	0	97	0.06	0	0	5.82	0	Negatively Pressurized
Headhouse	Science Laboratories	25	444	0.18	11.1	10	190.92	1400	0.136371429
Histology Teaching Lab	Science Laboratories	25	890	0.18	22.25	10	382.7	1200	0.318916667
Hot Lab	Science Laboratories	25	136	0.18	3.4	10	58.48	525	0.111390476
Individual Research Lab	Office Space	5	139	0.06	0.695	5	11.815	200	0.059075
Individual Research Lab	Office Space	5	139	0.06	0.695	5	11.815	200	0.059075
Individual Research Lab	Office Space	5	138	0.06	0.69	5	11.73	200	0.05865
Individual Research Lab	Office Space	5	135	0.06	0.675	5	11.475	200	0.057375
Individual Research Lab	Office Space	5	143	0.06	0.715	5	12.155	400	0.0303875
Isotope Storage	Storage Rooms	0	122	0.12	0	0	14.64	0	Negatively Pressurized
Lab Discussion	Conference Room	50	707	0.06	35.35	5	219.17	1000	0.21917
Lab Prep	Science Laboratories	25	981	0.18	24.525	10	421.83	1200	0.351525
Laser Support	Science Laboratories	25	161	0.18	4.025	10	69.23	400	0.173075
Machine Shop	Wood/Metal Shop	20	461	0.18	9.22	10	175.18	500	0.35036
Manager Office	Office Space	5	111	0.06	0.555	5	9.435	100	0.09435
Mechanical	Elevator Machine Rm	0	3688	0.12	0	0	442.56	0	Negatively Pressurized
Mechanical	Elevator Machine Rm	0	865	0.12	0	0	103.8	0	Negatively Pressurized
Men's Toilets	Storage Rooms	0	210	0.12	0	0	25.2	200	0.126
Men's Toilets	Storage Rooms	0	170	0.12	0	0	20.4	200	0.102
Microbiology	Science Laboratories	25	926	0.18	23.15	10	398.18	1100	0.361981818
Microscope Room	Science Laboratories	25	201	0.18	5.025	10	86.43	350	0.246942857
Microscope Room	Science Laboratories	25	138	0.18	3.45	10	59.34	300	0.1978
Modern Physics Lab	Science Laboratories	25	589	0.18	14.725	10	253.27	870	0.291114943

Networking Lab	Science Laboratories	25	558	0.18	13.95	10	239.94	1100	0.218127273
NMR Room	Science Laboratories	25	192	0.18	4.8	10	82.56	600	0.1376
Non-Majors Biology Teaching Lab	Science Laboratories	22	1100	0.18	24.2	10	440	1000	0.44
Non-Majors Prep	Science Laboratories	25	161	0.18	4.025	10	69.23	400	0.173075
Office	Office Space	5	115	0.06	0.575	5	9.775	100	0.09775
Open Computer Lab	College Laboratory	25	706	0.18	17.65	10	303.58	1000	0.30358
Physics Isotopes Lab	College Laboratory	25	126	0.18	3.15	10	54.18	300	0.1806
Physiology Teaching Lab	College Laboratory	25	921	0.18	23.025	10	396.03	940	0.421308511
Pick Up/Student	Office Space	5	101	0.06	0.505	5	8.585	100	0.08585
Pump Room	Elevator Machine Rm	0	54	0.12	0	0	6.48	500	0.01296
Recycling	Storage Rooms	0	96	0.12	0	0	11.52	0	Negatively Pressurized
Research Module	College Laboratory	25	129	0.18	3.225	10	55.47	0	Negatively Pressurized
Research Module	College Laboratory	25	129	0.18	3.225	10	55.47	0	Negatively Pressurized
Robotics Lab	College Laboratory	25	554	0.18	13.85	10	238.22	1100	0.216563636
Robotics Lab	College Laboratory	25	530	0.18	13.25	10	227.9	1100	0.207181818
Scanning Tunnel Microscope	College Laboratory	25	209	0.18	5.225	10	89.87	450	0.199711111
Seminar Room	Classroom	35	531	0.12	18.585	10	249.57	800	0.3119625
Seminar Room	Classroom	35	207	0.12	7.245	10	97.29	350	0.277971429
Seminar Room	Classroom	35	208	0.12	7.28	10	97.76	600	0.162933333
Shared Instrumentation	College Laboratory	25	155	0.18	3.875	10	66.65	250	0.2666
Shared Instrumentation	College Laboratory	25	211	0.18	5.275	10	90.73	400	0.226825
Shared Instrumentation	College Laboratory	25	152	0.18	3.8	10	65.36	600	0.108933333
Soil Sample Storage	Storage Rooms	0	194	0.12	0	0	23.28	300	0.0776
Stockroom	Storage Rooms	0	679	0.12	0	0	81.48	800	0.10185
Student Project Lab	College Laboratory	25	572	0.18	14.3	10	245.96	750	0.327946667
Student W/Up Space	Office Space	5	97	0.06	0.485	5	8.245	150	0.054966667
Student/Faculty Research	College Laboratory	25	813	0.18	20.325	10	349.59	1500	0.23306
Support	Office Space	5	212	0.06	1.06	5	18.02	300	0.060066667
Support	Office Space	5	208	0.06	1.04	5	17.68	300	0.058933333
Support	Office Space	5	202	0.06	1.01	5	17.17	300	0.057233333
Support	Office Space	5	160	0.06	0.8	5	13.6	300	0.045333333
Support Room	Office Space	5	206	0.06	1.03	5	17.51	350	0.050028571
Supporting Room	Office Space	5	203	0.06	1.015	5	17.255	300	0.057516667
Teledata	Electrical Equipment	0	115	0.06	0	0	6.9	300	0.023
Teledata	Electrical Equipment	0	113	0.06	0	0	6.78	300	0.0226
Teledata	Electrical Equipment	0	105	0.06	0	0	6.3	300	0.021
Teledata	Electrical Equipment	0	103	0.06	0	0	6.18	300	0.0206
Teledata	Electrical Equipment	0	111	0.06	0	0	6.66	500	0.01332
Toilet	Storage Rooms	0	47	0.12	0	0	5.64	100	0.0564
Toilet	Storage Rooms	0	47	0.12	0	0	5.64	100	0.0564
Toilet	Storage Rooms	0	47	0.12	0	0	5.64	100	0.0564
Toilet	Storage Rooms	0	47	0.12	0	0	5.64	100	0.0564
Toilet	Storage Rooms	0	47	0.12	0	0	5.64	100	0.0564
Toilet	Storage Rooms	0	47	0.12	0	0	5.64	100	0.0564
Toilet	Storage Rooms	0	46	0.12	0	0	5.52	100	0.0552
Toilet	Storage Rooms	0	46	0.12	0	0	5.52	100	0.0552
Undergraduate Space	Conference Room	50	314	0.06	15.7	5	97.34	400	0.24335
Undergraduate Space	Conference Room	50	306	0.06	15.3	5	94.86	400	0.23715
Undergraduate W/Up Space	Conference Room	50	290	0.06	14.5	5	89.9	250	0.3596
Undergraduate W/Up Space	Conference Room	50	298	0.06	14.9	5	92.38	350	0.263942857
Undergraduate W/Up Space	Conference Room	50	315	0.06	15.75	5	97.65	400	0.244125
Undergraduate W/Up Space	Conference Room	50	251	0.06	12.55	5	77.81	350	0.222314286
Vert/Anat/Dissec Teaching Lab	College Laboratory	25	909	0.18	22.725	10	390.87	1200	0.325725
Wet Specimen Storage	Storage Rooms	0	125	0.12	0	0	15	200	0.075
Women's Toilets	Storage Rooms	0	212	0.12	0	0	25.44	200	0.1272
Women's Toilets	Storage Rooms	0	161	0.12	0	0	19.32	200	0.0966
Wood & Plastic Shop	Wood/Metal Shop	20	123	0.18	2.46	10	46.74	250	0.18696