TECHNICAL REPORT THREE

MECHANICAL SYSTEMS
EXISTING CONDITIONS

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29 NOVEMBER 2010

PENN STATE UNIVERSITY ARCHITECTURAL ENGINEERING

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EXECUTIVE SUMMARY

This purpose of this report is to provide a summary of the existing design of the Unified Science Center, a teaching and research facility on the campus of the University of Scranton in Scranton, Pennsylvania. The building houses various departments within the University and its program includes office space, classrooms, laboratories, and computer rooms., and is designed for LEED Silver certification.

In this technical report, the mechanical systems of the Unified Science Center are analyzed and critiqued, drawing on information from previous technical reports as well as more recent studies.

The Unified Science Center is supplied with 100% outside air from (5) rooftop air handling units with energy recovery wheels, atomizing fog humidifiers, and variable volume supply fans. Analysis of these air handling units is included in this report with respect to ventilation and thermal comfort.

Chilled water is provided by (2) 550 ton chillers and (2) 550 ton cooling towers. Heating hot water is provided by (8) natural gas fired boilers. All of the HVAC equipment used in the Unified Science Center maintains a high degree of efficiency and sophistication.

The following report describes the mechanical systems of the Unified Science Center in detail, beginning with the design itself and moving on to costs and loads. It then provides a succinct description of the sequence of operations for airside and waterside systems, followed by an assessment of the mechanical systems with respect to LEED-NC 2009. Finally, an overall evaluation of the systems as designed is provided.

This report concludes that the mechanical systems of the Unified Science Center are extremely well designed and suited to the requirements of the project, though the costs associated with a 100% outside air system are significant. Nonetheless, the HVAC systems comply with relevant ASHRAE standards and provide a significant number of LEED points toward the goal of Silver certification.

MECHANICAL SYSTEMS DESCRIPTION

Introduction

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. New construction accounts for about 150,000 ft^2, and is seamlessly integrated with the renovation of an existing campus building. The building houses 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.

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 L-shaped building lends itself to a centralized HVAC system on the penthouse level. The architectural layout of the building is also conducive to efficiency of HVAC layout; 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 design of mechanical 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.

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%)	-

Table 1

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.

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

Table 2

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.

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

Table 3

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.

Water-Cooled Chillers							
	Capacity (Tons)	Efficiency (kW/Ton)		Evaporator (˚F)	Condenser (˚F)	Electrical	
		EER	NPLV	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

Table 4

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

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

Table 5

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:

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

Table 6

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

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

Table 7

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.

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**

Table 8

Mechanical Systems First Cost

Information pertaining to the first cost of the mechanical systems for the Unified Science Center was not 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.

Design Ventilation Requirements

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

	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

Table 9

Design Heating and Cooling Loads

In Technical Report 2 – *Building and Plant Energy Analysis*, heating and cooling loads were simulated using Trane TRACE. Table 10 shows the estimates produced by the software. The modeled values are generally similar to those in the design documents, with the notable exceptions of the heating load and the supply air rate for AHU 5. Difficulty in accurately modeling the complexities of the system likely accounts for these discrepancies; subsequent attempts to improve the model have not yielded significantly better results.

	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†	135	24	1.31	1.62	4.5

*Based on design square footage = 200,000 ft^2 (includes future expansion)
†Based on modeled square footage

Table 10

Annual Energy Consumption, Source Rates, and Costs

In Technical Report 2 – *Building and Plant Energy Analysis*, annual energy use was simulated using Trane TRACE. Table 11 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.

Annual Energy Consumption				
Load	Electricity (kWh)	Natural Gas (kBTU)	Water (1,000 gal)	% of Total
Heating				80
Primary		124,195,200		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

Table 11

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.

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

Table 12

Based on the modeled consumption and assumed utility rates, a comparison of annual energy costs is provided by Figure 1.

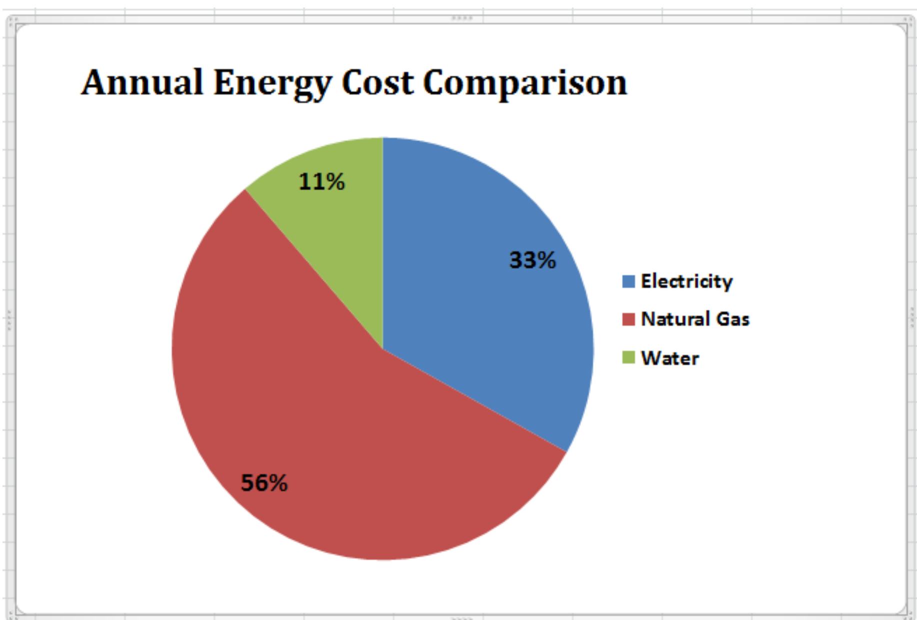

Fig. 1

MECHANICAL SYSTEMS OPERATION

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.

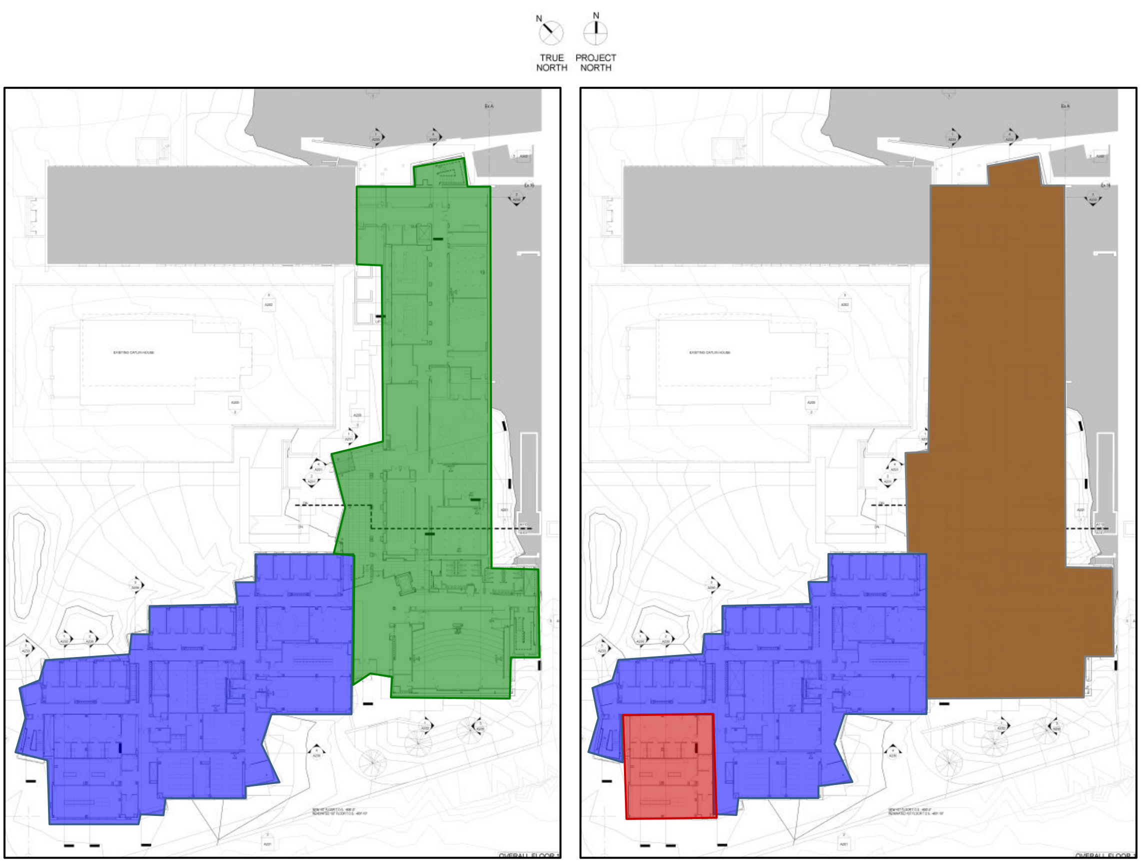

Fig. 1a Floors 1 – 4, typ. **Fig. 1b** Ground Floor

AHUs 1 and 2	AHUs 3 and 4	AHU 5

Fig. 2

Figure 3 shows the overall airflow diagram for the 5 air handling units. As indicated in the drawing, each AHU is located on the penthouse level, with exhaust fans located on the roof level above. Not shown in this figure due to space constraints is the outdoor air supplied to each AHU.

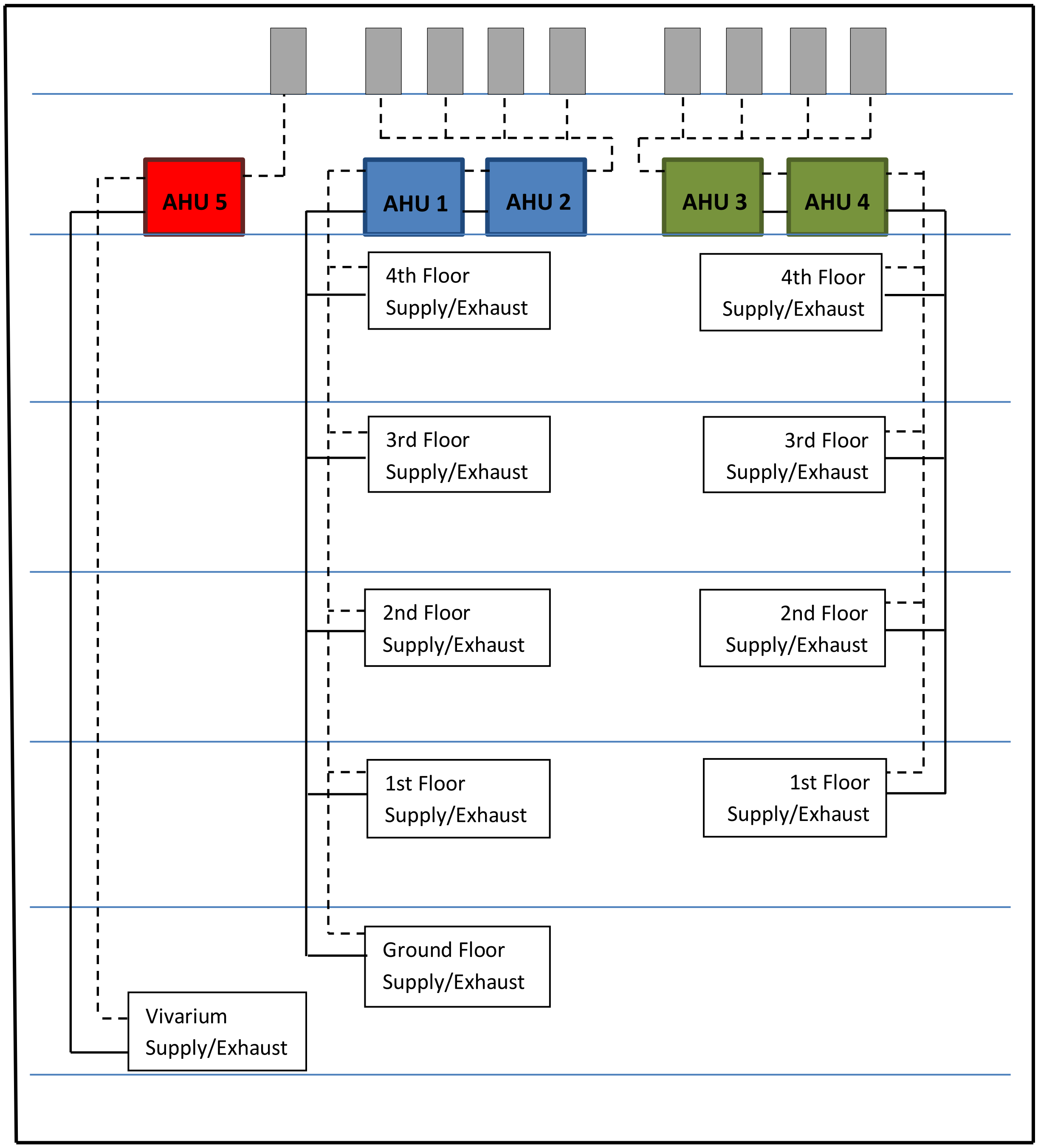

Fig. 3

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.

Figure 4 shows the typical configuration of each AHU:

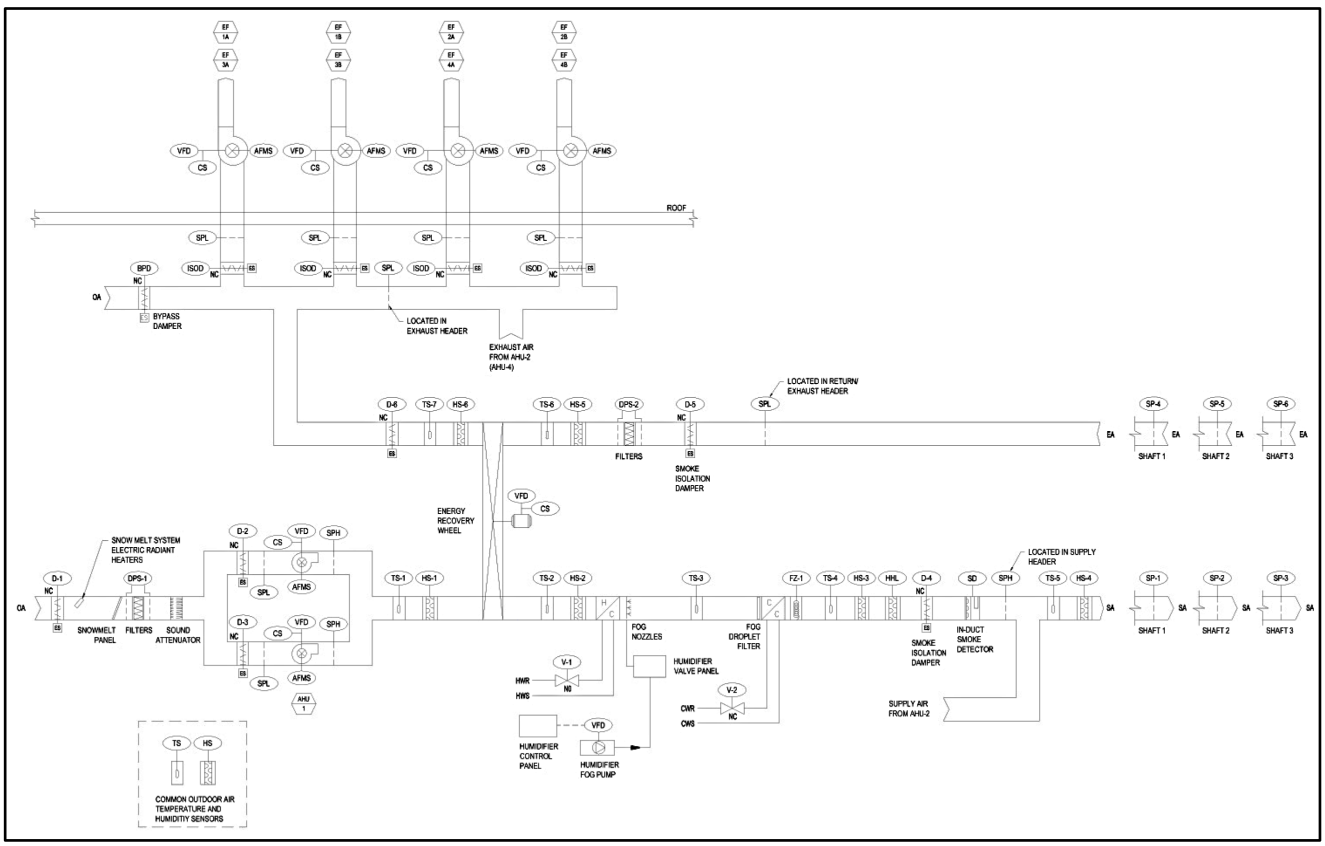

Fig. 4

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

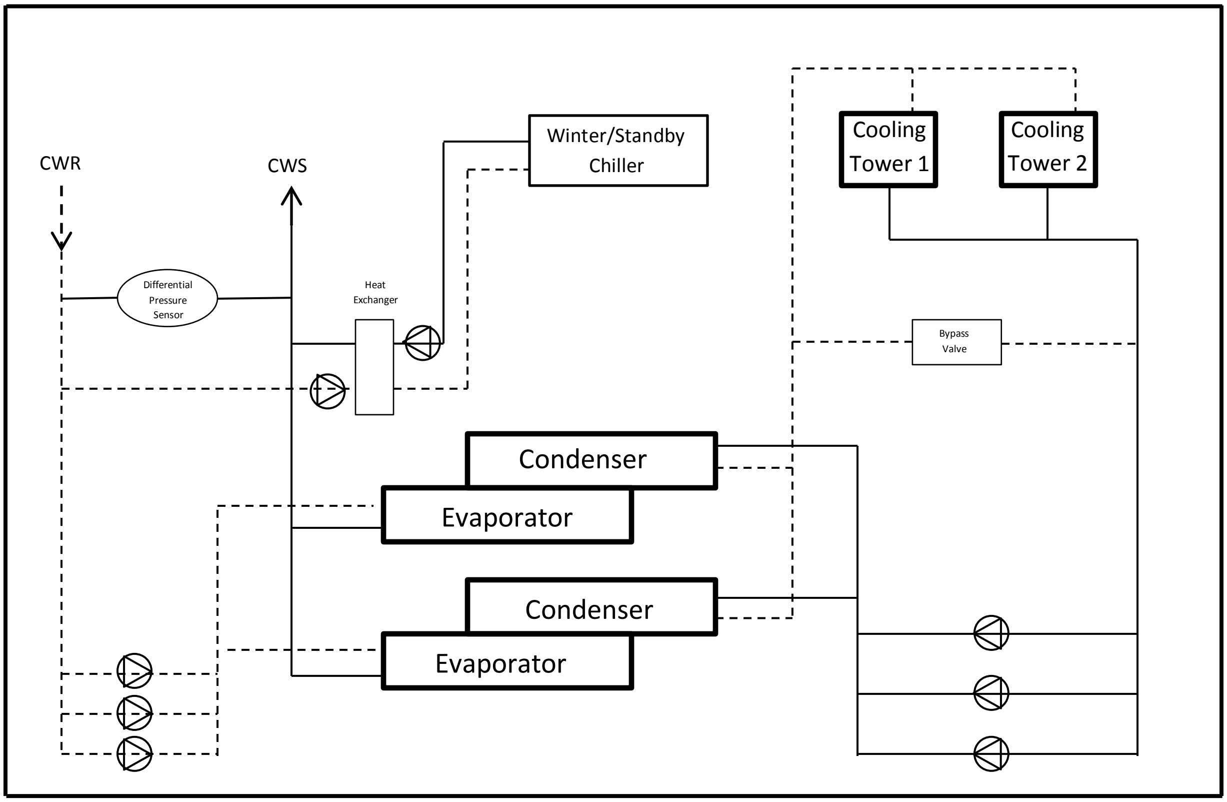
CWR
CWS
Winter/Standby
Chiller
Cooling
Tower 1
Cooling
Tower 2
Differential
Pressure
Sensor
Heat
Exchanger
Bypass
Valve
Condenser
Evaporator
Condenser
Evaporator

Fig. 5

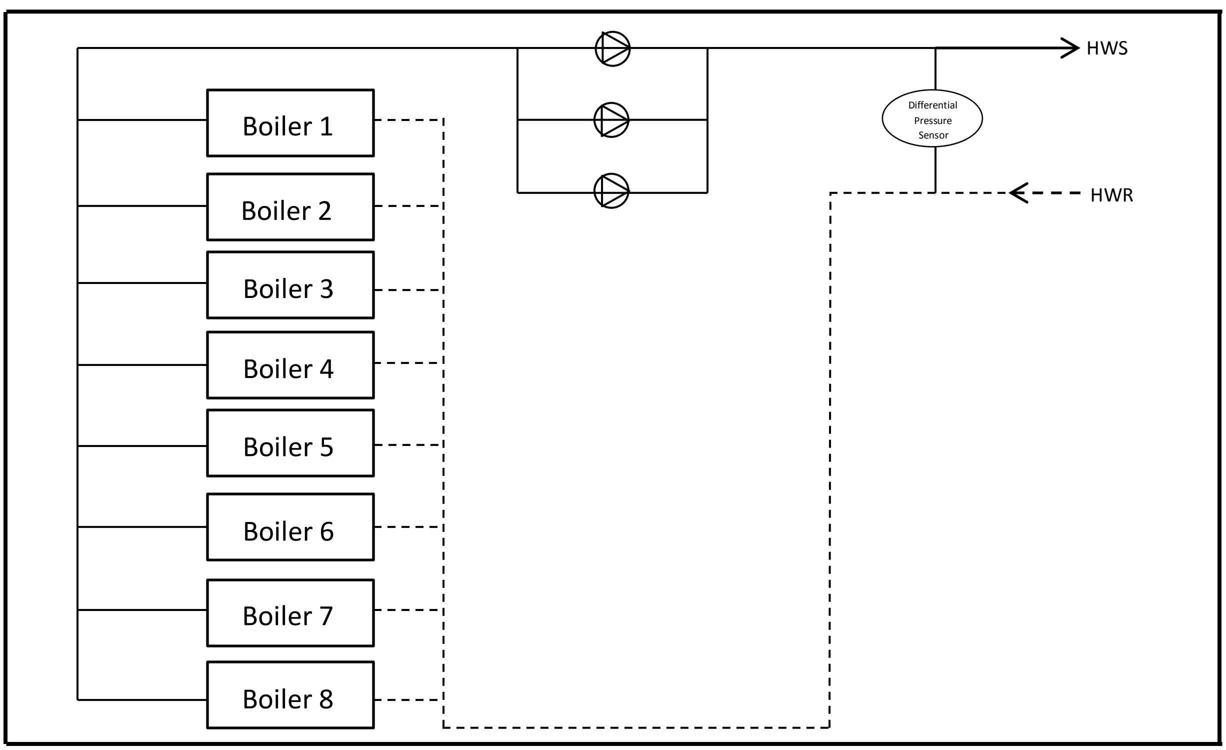
Boiler 1
Boiler 2
Boiler 3
Boiler 4
Boiler 5
Boiler 6
Boiler 7
Boiler 8
HWS
Differential
Pressure
Sensor
HWR

Fig. 6

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.

OVERALL EVALUATION

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.

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Project documentation provided by Einhorn Yaffee Prescott Architecture and Engineering.