NORTHEAST USA

INTEGRATED SCIENCES BUILDING

Technical Report III

System Operation Description

LEED Version 3 Evaluation

Overall System Evaluation

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Christopher S. Putman | Mechanical Option
Faculty Advisor | Dr. William Bahnfleth

Executive Summary

The Integrated Sciences Building is being constructed at an urban University campus in the Northeastern part of the United States and will be home to an educational and research laboratory facility that will include offices and classrooms. The building is intended to be a new icon of sustainability for the campus and the university.

The mechanical system of the Integrated Sciences Building is a Variable Air Volume (VAV) airside system with terminal reheat coils. The laboratory spaces will be 100% outside air systems to ensure air quality for the occupants and the research that occurs within the space. Serving the airside system will be dual 620-ton chillers on a Primary/Secondary chilled water system. Two 620-ton induced draft cooling towers will provide condensing capacity for the chiller plant. Heating will be provided via the district steam system. Steam heat exchangers will provide hot water to terminal reheat coils and a hot glycol mixture to the air handler heating coils. A glycol heat recovery system will conserve energy in the laboratory air systems by capturing heat, which would otherwise be wasted to the outdoors, and transferring it back to the incoming supply air.

The total mechanical cost of the building will be approximately $12 million, which is 23% of the overall building cost. This comes to about \$140/ ft^2 of usable occupied space within the building. Compared to typical mechanical systems and typical construction budgets, the mechanical systems of the building are in line with similar building types.

The Integrated Sciences Building is expected to receive a Gold rating for the United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) organization. This is considered the standard for quantifying a building's overall performance regarding sustainability. A LEED analysis was performed for the Energy and Atmosphere and the Indoor Environmental Quality portions of the version three rating system. Although the building engineers use the version 2.2 rating scale, version three was chosen as it is the most recent version of the LEED scale and it provided an opportunity for the user to compare the two rating systems in completing the analysis. The LEED analysis showed the design of the building achieved many goals of the LEED system with minimal effort. The points that were not easily attainable were done so for energy conservation purposes, with few points being chased for the sole purpose of LEED certification.

An overall system evaluation discusses the whether the building is viewed as a success based on the evaluation of this and previous technical reports. It was determined that the building was designed with sensible goals and very few obvious flaws. The task of making improvements will be a considerable challenge and that alone is justification for considering the building a success.

Mechanical System Overview

Design Objectives & Requirements

The Heating, Ventilation, and Air Conditioning (HVAC) system for the Integrated Sciences Building was designed to accomplish many different objectives. Obviously, comfort of the human occupants based on temperature and humidity were of foremost concern. Another main concern was to provide ventilation air of good quality, which is a more difficult task to achieve in buildings with science laboratories such as the Integrated Sciences Building. The system was designed to meet or exceed ASHRAE Standard 62.1 as well as ASHRAE Standard 90.1. Energy efficiency was another focus of utmost concern in order to reduce operating costs and minimize the carbon footprint of the building.

The building owner has an outline of minimum building performance requirements for all of its many construction projects. This building was required to follow those requirements, which apply to all areas of design and construction, including mechanical systems. In addition to those requirements, the owner wanted the Integrated Sciences Building to excel as an icon of energy efficiency. The original goal of the building was to become LEED Silver certified, but through the design phase, it is expected to reach LEED Gold status.

Finally, because the building is ultimately owned by a private educational organization, construction and operating costs are of great concern as well. The energy efficiency and comfort objectives were to be met in ways that made sense in a financial manner. A large emphasis in selecting systems was the ability to recoup the original installation and construction costs through energy and operational savings.

Design Conditions

Weather data used for the energy model of the Integrated Sciences Building was taken from the ASHRAE Handbook of Fundamentals for Philadelphia International Airport. This is the same weather data which was used by the design engineer. Below is Table 1, which shows the outside air design dry bulb temperatures for summer and winter as well as the summer wet bulb design temperature.

	Outside Design Conditions	
	Summer	Winter
OA Dry Bulb (°F)	92	0
OA Wet Bulb (°F)	75	N/A

Table 1 – Summer and Winter Outdoor Design Conditions

Indoor design conditions are shown in Table 2, which includes the summer and winter conditions. Relative humidity (RH) is also given and these numbers are limits. The summer relative humidity is a high limit and the winter relative humidity is a low limit. These temperatures and humidity levels were chosen based on human thermal comfort.

Space	Summer		Winter	
	Temp [°F]	RH	Temp [°F]	RH
General Teaching Lab	74	55%	72	30%
Office & Administration	75	55%	72	30%
Classrooms & Auditorium	75	55%	72	30%
Lobbies and Corridors	75	55%	72	30%
Research Laboratories	74	55%	72	30%

Table 2 – Summer and Winter Indoor Design set points.

Energy Sources & Rates

Energy sources that are available at the Integrated Sciences Building site include electricity supplied by the Pennsylvania Energy Company (PECO), Natural Gas supplied by Pennsylvania Gas Works, and purchased district steam supplied by Trigen. Energy price rates for these sources are shown below, in Tables 3-5.

Electricity (PECO - HT)	
Customer Monthly Charge	$291.43
Charge per kWh [Up to 150 kwh]	$0.0635
Charge per kWh [Up to 7,500,000 kwh]	$0.0442
Charge per additional kwh	$0.0253
Demand Charge per kW	$8.79

Table 3 – PECO Energy Rate Structure

District Steam (Trigen Rate S)	
Winter (October - May)	$/lb
Consumption: Charge per first 100 Mlbs	$29.08
Consumption: Charge per Additional Mlbs	$28.17
Demand: Charge per first 300 lb/hr	$1.84
Demand: Charge per next 39,700 lb/hr	$1.24
Demand: Chare per Additional lbs/hr	$1.09
Summer (June-September)	
Consumption: Charge per first 100 Mlbs	$27.78
Consumption: Charge per Additional Mlbs	$26.87
Demand: Charge per first 300 lb/hr	$0.00

Table 4 – Trigen District Steam Rate Structure

Natural Gas (Philadelphia Gas Works)	
Customer Monthly Charge	$18.00
Cost per Therm	$1.22

Table 5 – Philadelphia Gas Works Rate Structure

Site, Cost and Design Influences

The site location and energy sources for the Integrated Sciences Building were not difficult decisions during the initial design process. The location of the site was already under control of the building owner as a campus common area and outdoor green space. It is also in the heart of the rest of the urban campus. Upon visiting the site, it is easy to see that many of the other academic buildings under the same owner are all in the vicinity and within walking distance. Public transportation is also readily available via bus or train.

The availability of distributed steam to all of the buildings in that area is also ideal. As such, underground piping is already readily accessible and any costs associated with running steam piping to connect to a distributed system were not an issue. Since the relatively efficient nature of a distributed steam system, as well as the financial benefits of foregoing a new boiler purchase and installation, it was decided that purchased steam was the best source for heating energy.

As is the case with many new buildings, electric chillers were selected as a primary chilled water sources. The lack of a distributed chilled water system was one of the only factors to take into consideration. Electric chillers are ideal for building locations such as that of the Integrated Sciences Building because of their ability to run without considerable maintenance and extensively experience personnel that would have been required if the distributed steam was used in conjunction with absorption chillers.

Design Ventilation Requirements

An evaluation of the Integrated Sciences Building's ventilation systems was performed to determine whether the building will be in compliance with ASHRAE Standard 62.1-2007 upon completion. The laboratory air handler units (AHUs 5-8) provide 100% outdoor air to spaces with higher contaminant levels. As shown in Table 6, below, a comparison between the calculated minimum outdoor air requirements and the minimum design outdoor air confirms that all air handlers complied with the ASHRAE Standard 62.1-2007 requirements. Air handling units that were not 100% outdoor air are predominantly variable air volume (VAV) systems with terminal reheat. The minimum outside air requirements calculated by the design engineer were a result of various factors, including minimum air change rates for laboratories, shown in Table 7, International Mechanical Code (IMC) 2009 requirements, and building pressurization. The minimum air flow rates as outlined in Chapter 4 of the 2009 IMC were nearly identical to those specified in ASHRAE Standard 62.1-2007, which was a major factor in why the Integrated Sciences Building complied very well with the ASHRAE requirements.

Unit	Calculated Outdoor Air Required (62.1)	Maximum Design Supply Air	Minimum Design Outdoor Air	ASHRAE 62.1 Compliance
AHU-1	2257	6000	3400	Yes
AHU-2	2986	19000	9500	Yes
AHU-3	2305	16000	7800	Yes
AHU-4	2517	20000	6900	Yes
AHU-5	5206	42500	100% OA	Yes
AHU-6	4781	28000	100% OA	Yes
AHU-7	2466	27000	100% OA	Yes
AHU-8	5350	20000	100% OA	Yes
AHU-9	1030	12000	1200	Yes

Table 6 – ASHRAE 62.1-2007 Ventilation Compliance Evaluation (From Technical Report I)

	Minimum Laboratory Ventilation Rates [ACH]	
Operation Mode	Occupied	Unoccupied
Research Labs	10	6
Teaching Labs	8	4

Table 7 – Laboratory Air Change Rate requirements.

Design Heating & Cooling Loads

The following, Table 8, gives an outline of heating and cooling loads for each air handler. These values were calculating using a Trane TRACE 700 model for Technical Report II. As mentioned in that report, the values may include some error as a result of the user's inexperience with energy modeling. There were several factors that may have influenced the numbers to be high or low which were explained in the Technical Report II. However, the table does give a good idea of how the laboratory spaces have high air flows, which consists of a 100% outside air supply of air. This results in higher heating and cooling loads in the summer and winter months. The atrium also shows high loads due to the possibility of incorrect modeling, coupled with a high air flow rate for building pressurization.

Zone	Data Source	Cooling Load [ft^2/ton]	Heating Load [Btu-h/ft^2]	Total Supply Air [CFM/ft^2]	Ventilation Supply Air [CFM/ft^2]
AHU-1 (Auditorium)	Model	86.54	157.6	2.19	1.23
	Design	-	-	2.17	1.23
AHU-2 (Lecture Halls)	Model	184.7	83.02	2.07	1.21
	Design	-	-	2.44	1.22
AHU-3 (Atrium)	Model	464.9	45.24	1.22	0.52
	Design	-	-	1.62	0.81
AHU-4 (Offices)	Model	202.9	117.47	1.25	0.82
	Design	-	-	1.62	0.81
AHU-5 (Research Labs)	Model	64.2	228.97	2.50	2.50
	Design	-	-	2.56	2.56
AHU-6 (Research Labs)	Model	103.3	137.84	2.36	2.36
	Design	-	-	2.45	2.45
AHU-7 (Teaching Labs)	Model	110.9	93.66	2.21	2.21
	Design	-	-	3.57	3.57
AHU-8 (Teaching Labs)	Model	167	74.18	1.17	0.17
	Design	-	-	1.59	1.59
AHU-9 (Electrical & Data)	Model	372.5	20.49	1.53	0.21
	Design	-	-	1.37	0.25

Table 8 – Design Heating & Cooling loads from Technical Report II Trane TRACE 700 Simulation.

The design engineer did not provide actual calculated heating and cooling loads to be included in Technical Reports II or III. However, the engineer is currently working to report numbers for the purpose of this project so that any redesign can be analyzed against those numbers. Before a redesign of any mechanical systems is performed, the TRACE 700 model for energy calculations will be modified to more accurately match those of the design engineer.

Annual Energy Use & Cost

As the building is under construction at the time of this report, no actual energy usage for the Integrated Sciences Building was available. However, to quantify an estimate of the annual energy consumption of the building, information for Technical Report II can be re-examined.

Trane TRACE 700 software was used to measure anticipated cooling, heating, and ventilation loads of the Integrated Sciences Building also has the ability to estimate annual operating costs based on yearly weather data, utility rates, and equipment characteristics. The results of this calculation are shown below in Table 9. The energy usage is shown in kwh of electricity, kbtu of purchased district steam, and therms of natural gas. To gauge the amount of energy usage as a percentage of total building consumption, all energy units were converted to kbtu for the year. Percentages of total building load are shown.

When examining the information in the table, it can be seen that the largest portion of energy consumption according to the energy model is through heating of the building. Electricity for cooling, electrical loads, and fans is also a major energy load for the building. This is common for buildings in an area of the United States where winters are in the freezing range and summers are in the upper 90°F range with high latent loads.

Energy Consuming Function		Consumption Units		Equivalent Units		% of Total Use
Primary Heating						
	Primary Heating Coils	3565486	kBtu	5389991	kBtu	29%
	Heating Accessories	78086	kwh	266429.4	kbtu	1%
Primary Cooling						
	Cooling compressor	352,908	kwh	1204122	kbtu	6%
	Tower/Cond Fans	99766	kwh	340401.6	kbtu	2%
	Condenser Pump	98206	kwh	335078.9	kbtu	2%
	Other Cooling Accessories	121,539	kwh	414691.1	kbtu	2%
Auxiliary						
	Supply fans	563656	kwh	1923194	kbtu	10%
	Pumps	154586	kwh	527447.4	kbtu	3%
	Stand-Alone Base Utilities	37,724	kwh	128714.3	kbtu	1%
Lighting						
		368,045	kwh	1255770	kbtu	7%
Receptacle Loads						
		1,375,322	kwh	4692599	kbtu	25%
Fume Hood Natural Gas						
		23,706	therms	2370600	kbtu	13%
			Total Usage	18849038	kbtu	100%

Table 9 – Annual Energy Consumption totals by end use.

To understand the implications of the energy usage shown above, total annual energy consumption by source is shown below in Table 10 along with the total energy cost by source along with a comparison of the energy usage and costs as presented by the design engineer's energy analysis. As mentioned in previous technical reports, error in the energy analysis could be a result of incorrect fume hood exhaust modeling as well as error in modeling the unusual building pressurization methods. This error will be investigated thoroughly before analyzing the cost effectiveness of any redesign to ensure accurate justification of modifications to the design of the building.

	TRACE 700 Model		Design Model		ASHRAE 90.1-2004 Baseline Model	
	Annual Consumption	Annual Cost	Annual Consumption	Annual Cost	Annual Consumption	Annual Cost
Electricity	3,249,838 kwh	$ 257,543.00	4,984,300 kwh	$ 367,933.00	5020250 kwh	$ 369,182.00
Purchased Steam	3,565,486 kBtu	$ 76,765.68	5,132,000 kBtu	$ 110,637.00	12939000 kBtu	$ 278,973.00
Natural Gas	23,706 Therms	$ 28,921.00	23,706 Therms	$ 28,921.00	23,706 Therms	$ 28,921.00
Total Annual Cost	-	$ 363,229.68	-	$ 507,491.00	-	$ 677,076.00
Annual Cost/ft^2	-	$ 2.63	-	$ 3.68	-	$ 4.91

Table 10 – Total Building Energy use simulation results by energy source type & annual operating costs.

Equipment Schedules

Air Handlers

The air handling units used for the Integrated Sciences Building are each of unique size and capacity, designed to match the spaces they serve. In Table 11, a list of pertinent air handler information is listed.

AHU Tag	Supply Fan Capacity [CFM]	Minimum Outside Air [CFM]	Return Fan Capacity [CFM]	Cooling Coil Capacity [MBH]	Heating Coil Capacity [MBH]	Glycol Heat Recovery Coil Capacity [MBH]
AHU-1	6000	3400	N/A	259	206	N/A
AHU-2	19000	9500	9500	994	631.4	N/A
AHU-3	16000	7900	8100	1190	1244	N/A
AHU-4	20000	10000	9600	924	864	N/A
AHU-5	42500	100%	N/A	3123	2754	1261.4
AHU-6	28,000	100%	N/A	2046	1878	831
AHU-7	27000	100%	N/A	1963.2	1835	801.3
AHU-8	20000	100%	N/A	1448.4	1338	593.6
AHU-9	12000	2000	12000	942	N/A	N/A

Table 11 – Air Handler Unit Schedule showing supply air, heating, and cooling capacities.

Note that, as has been discussed in other sections of this report as well as in previous technical reports, air handler unit 9 has no heating coils and is for cooling only. Air handlers 5-9 are 100% outdoor air units and have glycol heat recovery coils as an energy saving measure.

Chilled Water Plant

Chiller information is listed in Table 12. Both chillers are water-cooled centrifugal chillers manufactured by York. They are located in the mechanical penthouse. The condenser water is cooled by the Cooling Towers, listed in the Table 13. The cooling towers are direct, induced draft cooling towers manufactured by Baltimore Aircoil Company.

Chiller Schedule								
Chiller	Type	Nominal Capacity [Tons]	kW/Ton	Model	Two-Pass Evaporator		Two-Pass Condenser	
					EWT [°F]	LWT [°F]	EWT [°F]	LWT [°F]
CH-1,2	Water Cooled Centrifugal	620	0.632	York YKGQEVP8-CTG	56	42	85	97

Table 12 – Chiller Information

Cooling Tower Schedule							
Cooling Tower	Nominal Capacity [Tons]	Water Flow [gpm]	Wet Bulb EAT [°F]	EWT [°F]	LWT [°F]	Fan Capacity [CFM]	Model
CT-1,2	620	15550	78	97	85	149,090	Baltimore Aircoil Company 3604C

Table 13 – Cooling Tower Information

Hot Water Heat Exchangers

The following, Table 14, lists information about the four heat exchangers that use district steam to heat the building. Two of the heat exchangers heat a 30% glycol mixture and the other two are hot water.

Steam Heat Exchanger Schedule								
	Process - Side 1				Service - Side 2			Model
	Fluid	EWT [°F]	LWT [°F]	GPM	Fluid	Pressure [psi]	Capacity [lbs/hr]	
HE-1	30% P.G.	150	180	340	Steam	12	5105	Taco E12210-S
HE-2	30% P.G.	150	180	340	Steam	12	5105	Taco E12210-S
HE-3	Water	150	180	290	Steam	12	4474	Taco E10208-S
HE-4	Water	150	180	290	Steam	12	4474	Taco E10208-S

Table 14 – Steam Heat Exchanger information.

Major Pumps

All pumps listed below, Table 15, are from the manufacturer Bell & Gossett. Glycol mixing tank pumps are not listed but are shown on the schematics. They were not selected by the design engineer and are a part of the glycol mixing tank subcontract package.

Pump Tag	Service	GPM	Head [ft]	Motor		Notes
				HP	RPM	
P-1	Primary Chilled Water Pump (Duty)	1100	50	20	1750	-
P-2	Primary Chilled Water Pump (Duty)	1100	50	20	1750	-
P-3	Primary Chilled Water Pump (Standby)	1100	50	20	1750	-
P-4	Condenser Water Pump (Duty)	1550	90	50	1770	-
P-5	Condenser Water Pump (Duty)	1550	90	50	1770	-
P-6	Condenser Water Pump (Standby)	1550	90	50	1770	-
P-7	Secondary Chilled Water Pump (Duty)	1100	76	40	1150	VSD
P-8	Secondary Chilled Water Pump (Duty)	1100	76	40	1150	VSD
P-9	Secondary Chilled Water Pump (Standby)	1100	76	40	1150	VSD
P-10	Glycol Heating Pump (Duty)	340	100	20	1750	VSD
P-11	Glycol Heating Pump (Duty)	340	100	20	1750	VSD
P-12	Hot Water Heating Pump (Duty)	290	95	15	1750	VSD
P-13	Hot Water Heating Pump (Standby)	290	95	15	1750	VSD
P-14	AHU-1 Glycol Circulating Pump	14.3	30	0.4	3250	-
P-15	AHU-2 Glycol Circulating Pump	43.8	30	1	1750	-
P-16	AHU-3 Glycol Circulating Pump	86.4	30	2	1150	-
P-17	AHU-4 Glycol Circulating Pump	60	30	1.5	1750	-
P-18	AHU-5 Glycol Circulating Pump	190	30	3	1150	-
P-19	AHU-6 Glycol Circulating Pump	129	30	2	1750	-
P-20	AHU-7 Glycol Circulating Pump	125	30	2	1750	-
P-21	AHU-8 Glycol Circulating Pump	92	30	1.5	1750	-
P-22	Primary Glycol Heat Recovery Pump (Duty)	300	90	15	1750	VSD
P-23	Primary Glycol Heat Recovery Pump (Standby)	300	90	15	1750	VSD
P-24	Secondary Glycol Heat Recovery Pump (Duty)	100	60	5	1750	-
P-25	Secondary Glycol Heat Recovery Pump (Standby)	100	60	5	1750	-
P-26	AHU-5 Heat Recovery Booster Pump	99	30	2	1750	-
P-27	AHU-6 Heat Recovery Booster Pump	65	30	1.5	1750	-
P-28	AHU-7 Heat Recovery Booster Pump	64	30	1.5	1750	-
P-29	AHU-8 Heat Recovery Booster Pump	47	30	1.5	1750	-

Table 15 – Pump characteristic and motor information.

Building System Operation

Air Side Systems

Air side system can be separated into two main types for the Integrated Sciences Building: those that serve laboratory spaces, and those that do not.

The non-laboratory air handlers are conventional variable air volume (VAV) systems with terminal reheat. All supply and return fans are equipped with variable speed drives. System startup is based on the building automatic system time of day schedule. Upon startup, the outside air intake and exhaust air dampers open. When the variable speed drives are activated and proof of flow is confirmed, the fans speed up and bring the system to modulating control. In cooling mode, zone controllers send requests to the air handler to modulate the supply air temperature by means of adjusting the cooling coil control valve. Airside free cooling is activated when all heating commands are zero and the outside air temperature is less than 65°F.

The laboratory air handling units do not have return fans, but instead exhaust fans which send air directly to the outdoors. These exhaust fans are equipped with glycol heat recovery coils that preheat new supply air that is 100% outdoor air. All fans on these systems are equipped with variable speed drives so that the amount of air supplied to and extracted from the spaces can be modulated based on the minimum air change rates for laboratories for occupied and unoccupied hours. These schedules are assigned by the Building Automation System upon system setup. More information on the glycol heat recovery system, as well as a schematic can be seen in the water-side portion of this section. The temperature control of the spaces is achieved by conventional variable air volume coil controls such as those described for the non-laboratory airside systems. Table 16 gives details on operation and features of the air handlers.

Unit	Mixing Box	30% Filter	90% Filter	Heat Recovery Coil	Glycol Heating Cool	Chilled Water Cooling Coil	Reheat Coil	Steam Injection Humidifier	Supply Fan	Return Fan
1	X	X	X		X	X	X		VAV	VAV
2	X	X	X		X	X			VAV	VAV
3	X	X	X		X	X			VAV	VAV
4	X	X	X		X	X			VAV	VAV
5		X	X	X	X	X		X	VAV	
6		X	X	X	X	X		X	VAV	
7		X	X	X	X	X		X	VAV	
8		X	X	X	X	X		X	VAV	
9	X	X	X		X	X			CAV	

Table 16 – Air Handler features by unit.

Water Side Systems

Chilled Water System

The chilled water system is a Primary-Secondary system. There are two 620-ton water cooled, centrifugal chillers. The condenser water system includes two 620-ton induced draft cooling towers. The condenser water pumps and the primary chilled water pumps are operate at constant volume while the secondary chilled water pumps are equipped with variable speed drives. The chiller water system initiates when the outside air temperature rises above 55°F. There are three condenser water pumps, with one as a standby and two which operate in alternation. The cooling tower fans are controlled by the cooling tower leaving water temperature. They activate and increase in speed via variable frequency drive when the leaving water temperature rises above the set point. The cooling tower leaving water set point is either 65°F or the outside air wet bulb temperature plus the 12°F cooling tower approach, whichever is higher. Primary Chilled water pumps cycle to meet the load of the chilled water system and to maintain an acceptable pressure drop between supply and return.

Steam & Hot Water

The heating needs of the building are served by a 200 psi distributed steam system. There are two pressure reducing stations from 200 psi to 60 psi and then 60psi to 12 psi. The 12 psi steam goes to four heat exchangers. Two of the heat exchanges are steam to glycol mixture while the other two are steam to hot water. The heated glycol mixture is distributed to the air handler heating coils. The hot water is distributed to the reheat coils. Some steam is also sent to direct injection humidifiers in the laboratory air handlers as well as domestic hot water heating tanks. Condensate waste heat is utilized in the glycol heat recovery system.

The glycol heating system consists of a 30% glycol-water mixture that enters the heat exchangers are 150°F and leaves at 180°F. The mixture is heated in steam heat exchangers 1 and 2 and sent to the air handler heating coils. The flow through the heating coils is controlled by a temperature sensor of the air downstream of the heating coil in the air handler. This is not shown on the schematic. Pumps 10 and 11 provide flow through the system and each are equipped with a variable frequency drives. Pump flow is controlled to maintain a differential in pressure between the supply and return headers. Flow based on capacity is controlled by increasing pump energy to meet the set point and pressure differential set point. Overall system heat consumption is measured using temperature sensors upstream and downstream of the heat exchangers and the flow measure quantity of water through the heat exchangers.

The hot water heating system that serves the terminal reheat coils operates in much the same way as the glycol heating system except that water is distributed to the VAV box coils rather than air handlers. Pumps 12 and 13 provide pumping for the system and are alternated to equalize run times. One pump is designated the “lead” pump and the other the “standby” pump. These pumps are also controlled in the same way as the glycol heating system.

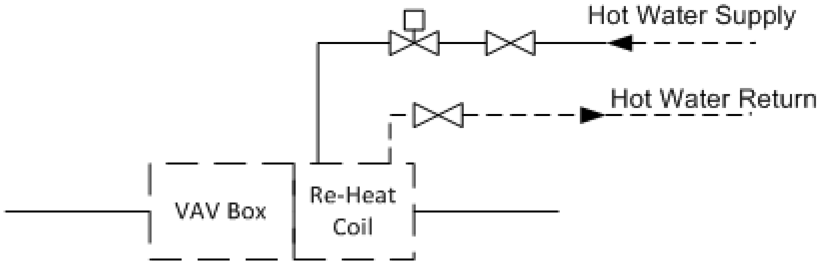
Glycol Heat Recovery

The glycol heat recovery system captures energy from the exhaust air streams of the laboratory and its fume hood exhaust. Pumps 22 and 23 are the primary pumps for the system, and operate at constant volume. Pimps 24 and 25 integrate a steam condensate heat recovery loop that uses waste heat from the steam system condensate to help with energy recovery. Both sets of pumps alternate such that one is the “lead” and one is “standby” in order to equalize run times. Booster pumps circulate water though the glycol heat recovery heating coils in the laboratory air handlers. A mixing valve modulates flow through the coil and the bypass based on air temperature downstream of the coil and the leaving glycol mixture temperature.

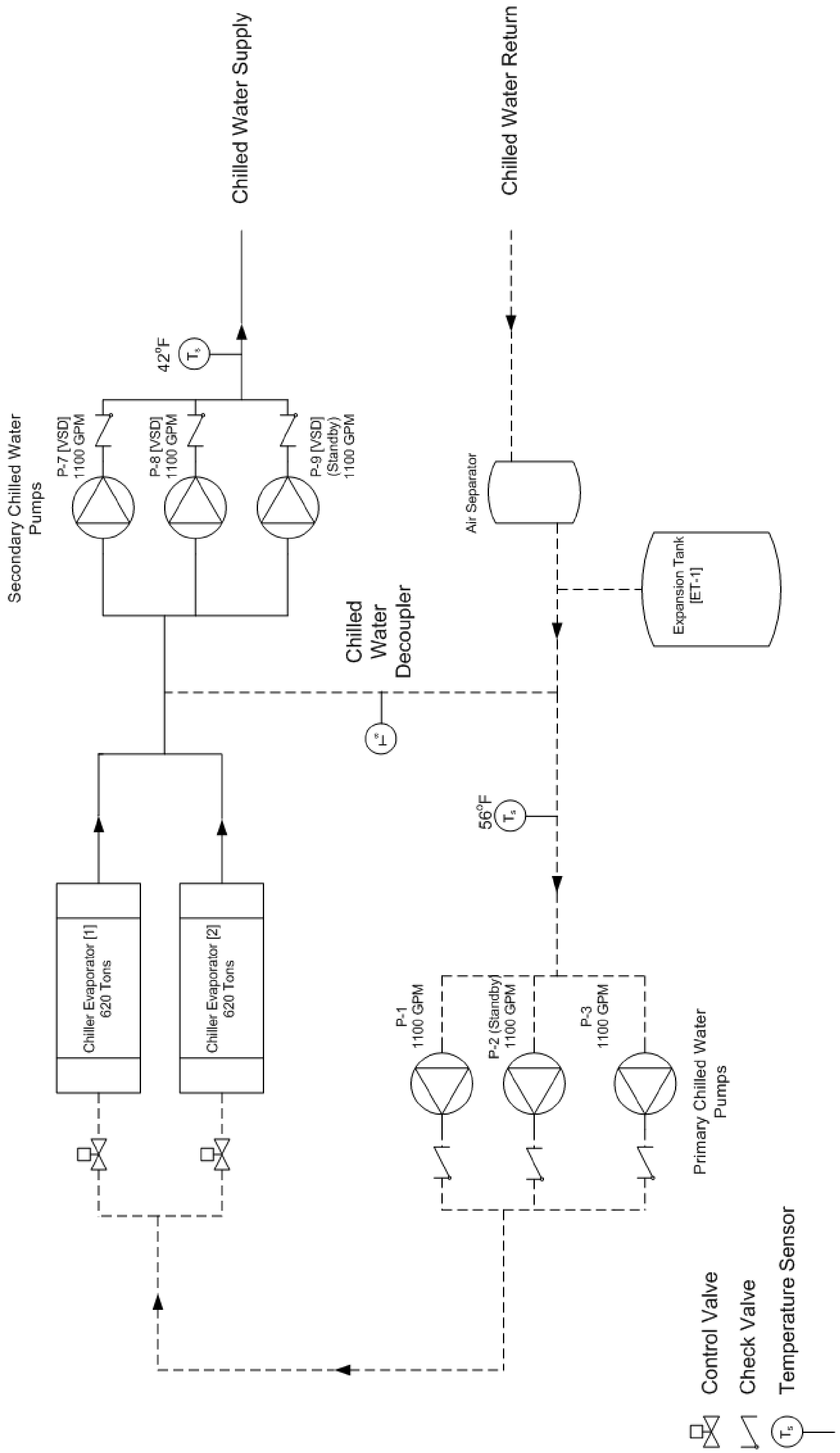
System Schematics

The following illustrations are schematics of different equipment and systems of the Integrated Sciences Building. The purpose of the schematics is to convey the general arrangement of how the systems that have been described actually work. They are not intended to show all isolation valves and specific fittings that are required for installation and operation. The intention was to display the schematic design as was illustrated in the design drawings, and to do so in a way that is easy to visualize.

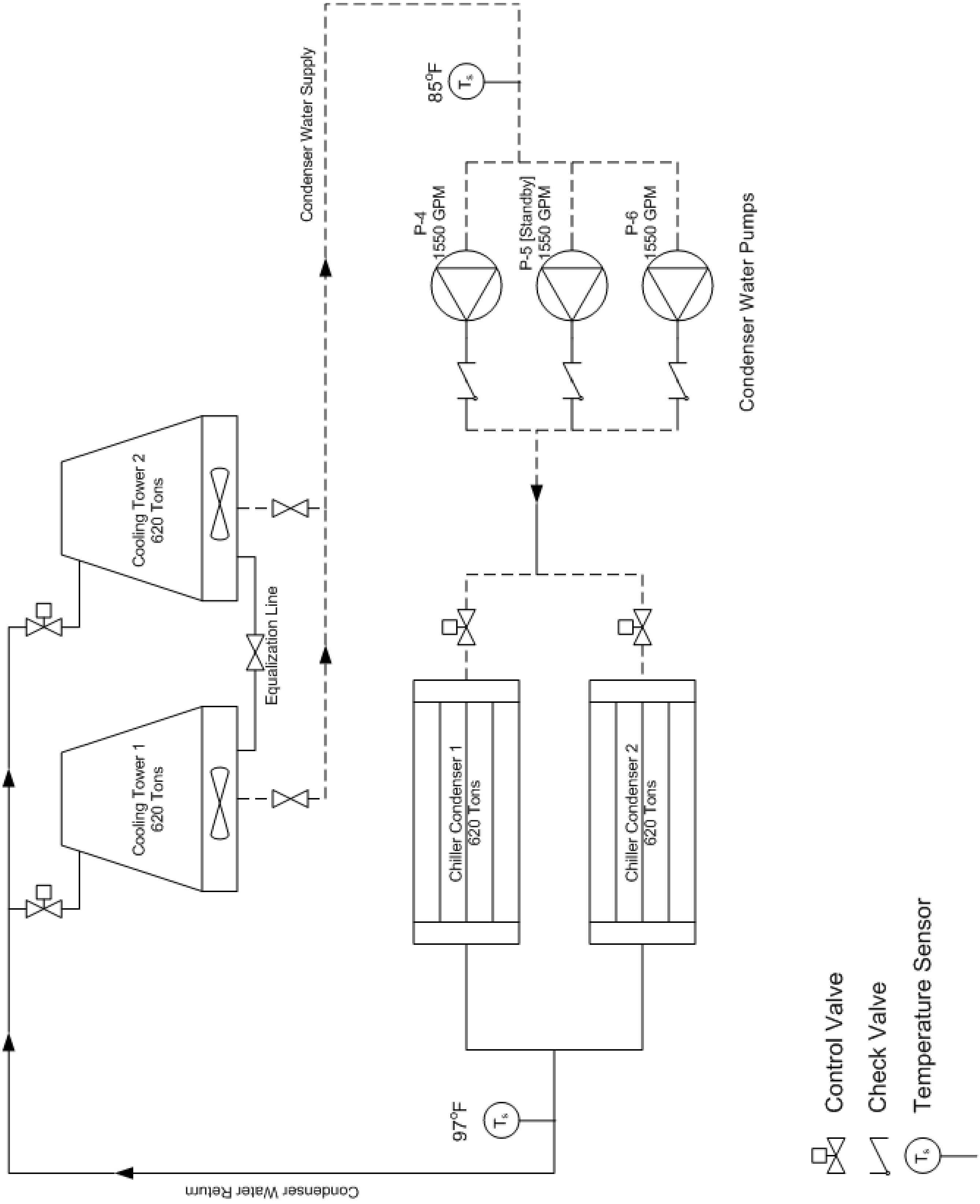
Schematic – VAV Terminal Box



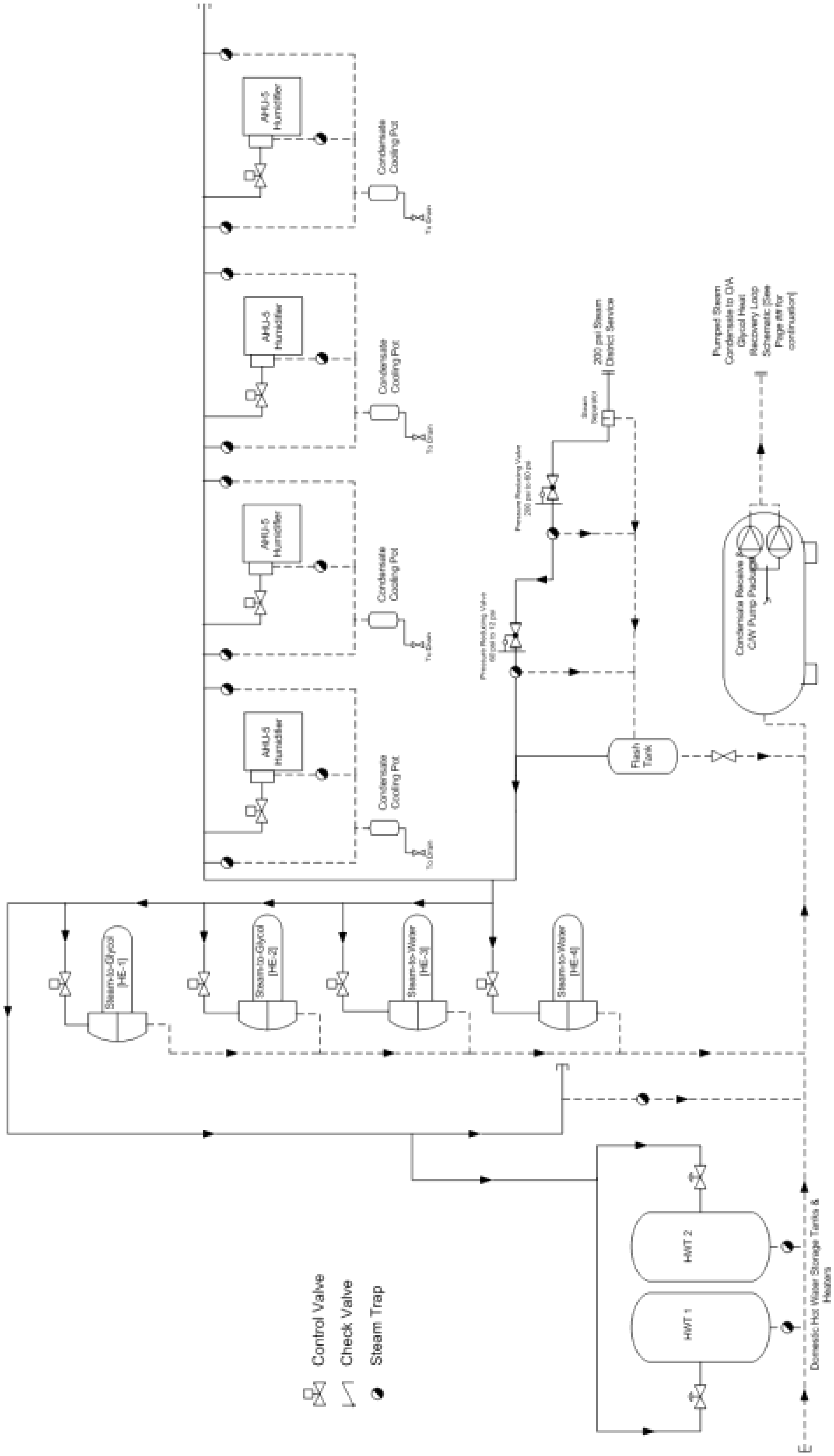
Schematic Drawings – Chilled Water System (Evaporator Side)



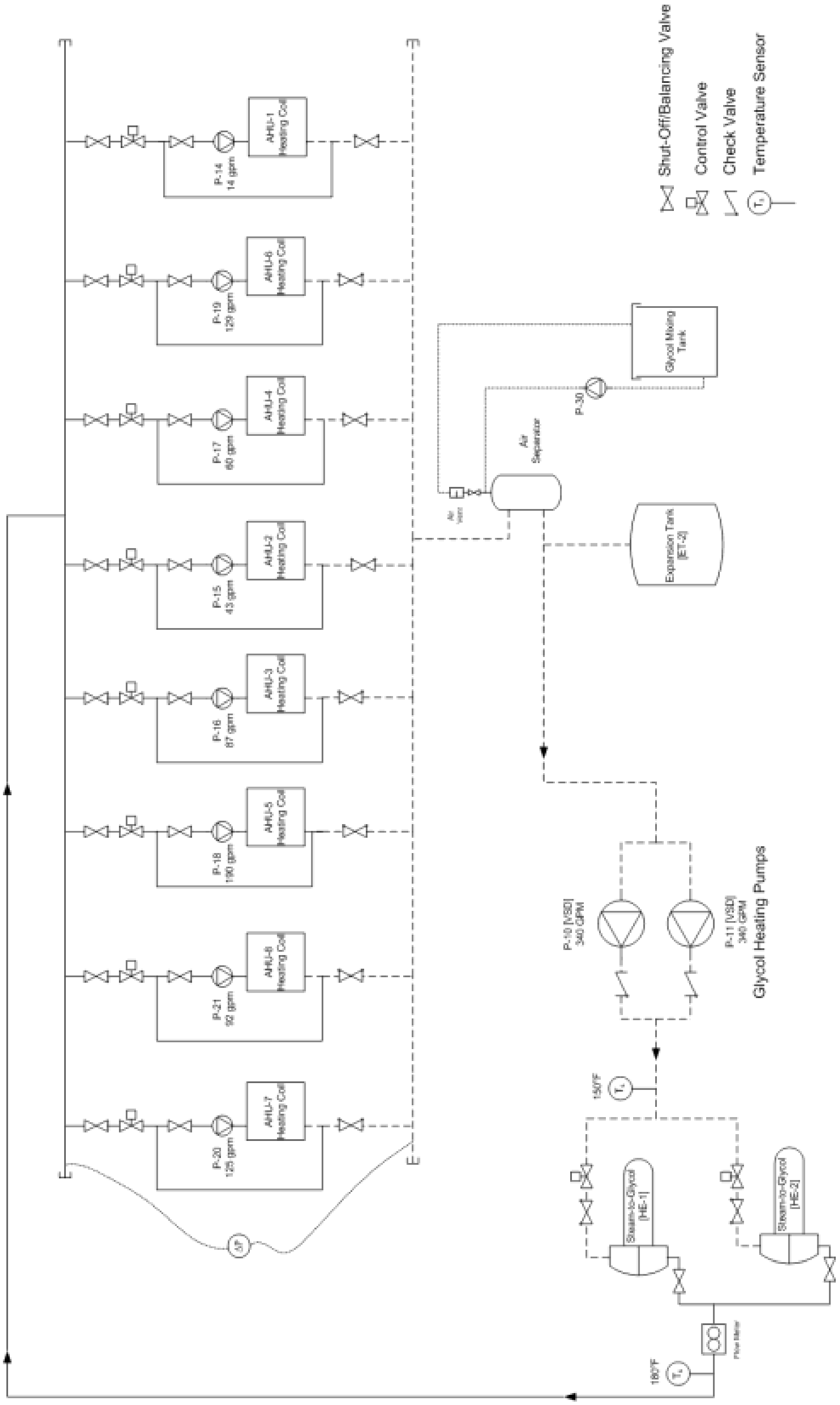
Schematic Drawings – Chilled Water (Condenser Water Side)



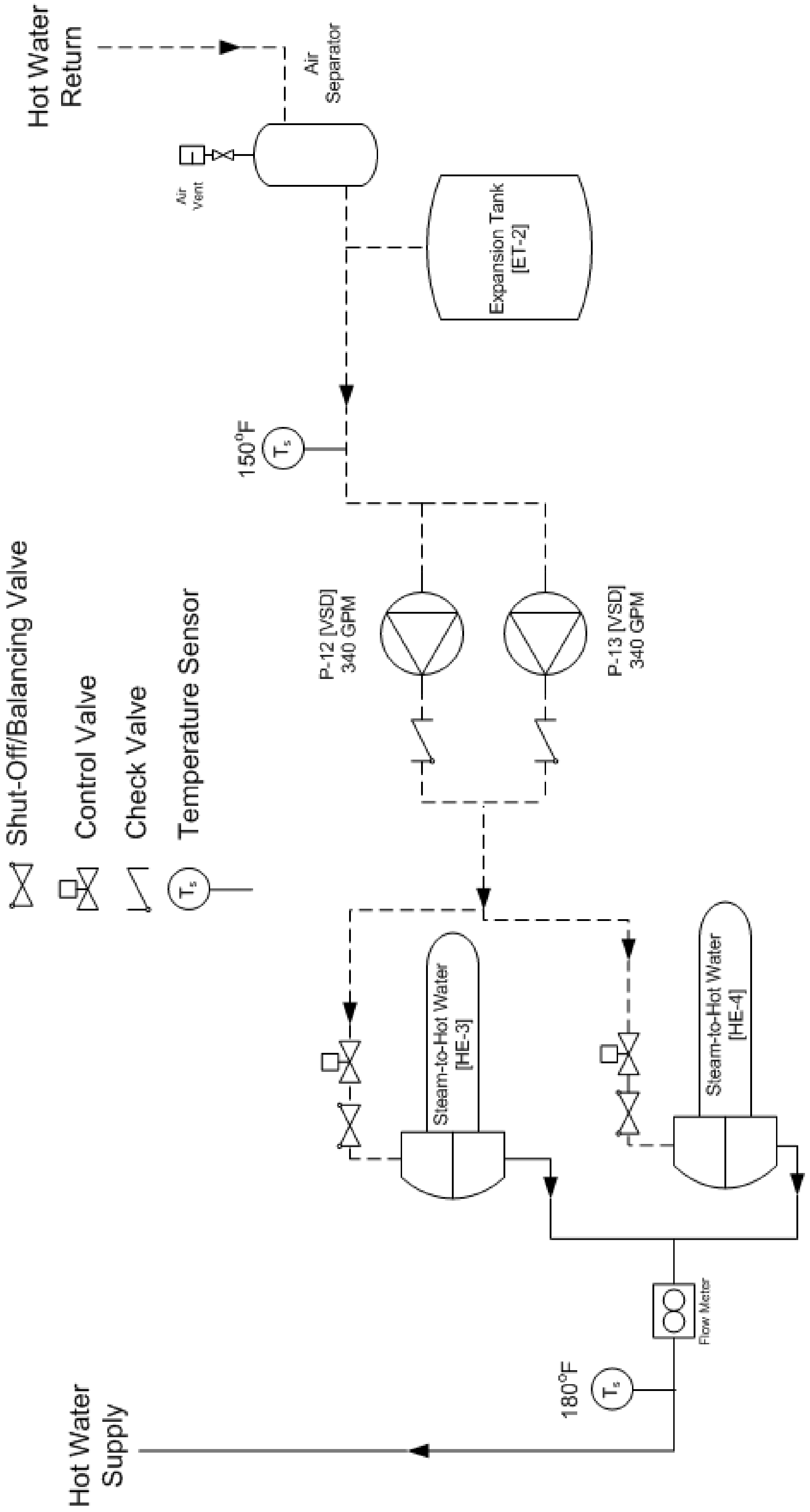
Schematic Drawings – Steam System



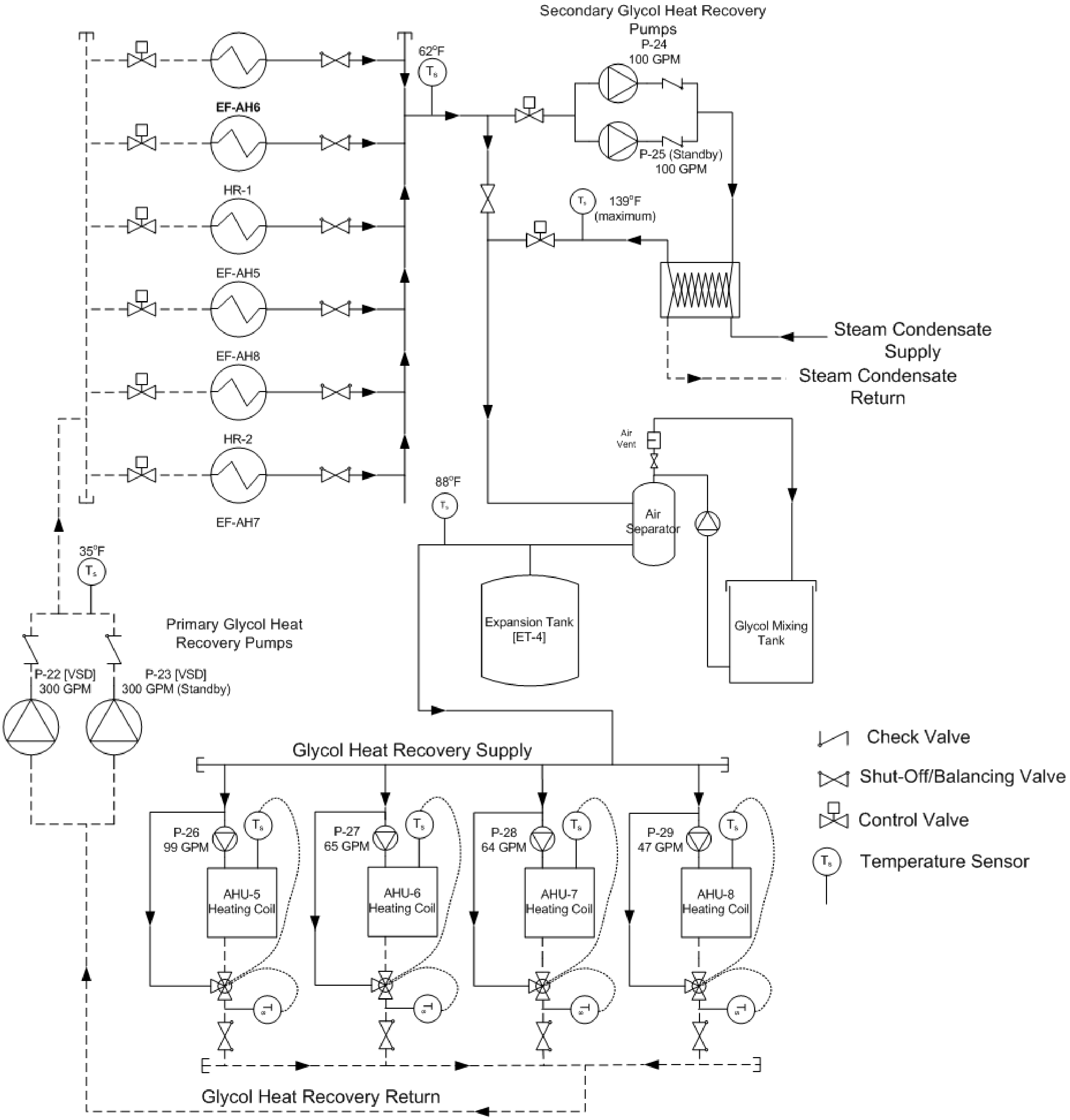
Schematic Drawings – 30% Glycol Heating System



Schematic Drawings – Hot Water Heating System



Schematic Drawings – 30% Glycol Heat Recovery Heating System



Lost Usable Space for Mechanical Systems

Below, Table 17 shows a tabulation of the floor area which is lost to mechanical systems and equipment. There is a pump room located in the basement for fire protection systems as well as steam heat exchangers, domestic hot water tanks, a steam condensate tank. The mechanical penthouse on the 5th level of the building holds the air handling units. The chilled water system is also in the penthouse, along with the chiller condenser water system and cooling towers. The area lost to mechanical systems on levels one through four is predominantly shaft space for HVAC ducts and piping. Since the air handlers are located on the roof penthouse, ducts go from the top of the building down to the floors which they serve. This is why shaft space decreases as a descent is made from the upper levels to the ground level. It should be noted that the penthouse space is not conditioned like other indoor spaces and is not necessarily lost usable space that could be used by occupants. Also, the building is used by the owner and space does not necessarily mean rent dollars are lost. However, the mechanical space is costly and eliminating space could reduce building costs.

Mechanical Space			
Level	Shaft Area [ft^2]	Mechanical Room Area [ft^2]	Total Area (Shaft + Room) [ft^2]
Basement	398	1499	1897
1st Floor	97	0	97
2nd Floor	453	0	453
3rd Floor	568	0	568
4th Floor	574	0	574
5th Floor	420	4393	4813
Penthouse	0	10432	10432
Overall Building	2510	16324	18834

Table 17 – Lost Usable space to mechanical equipment.

Mechanical System Cost

The total cost of the plumbing and mechanical system for the Integrated Sciences Building is estimated at $ 11,940,000. Due to the nature of the construction schedule and confidentiality of the pricing, a more detailed breakdown of these costs was not available. This price includes design and construction of the plumbing and mechanical systems. When compared to the overall building construction estimate of $51,100,000, this price is roughly 23% of the total building cost and yields a cost of about $86.52/ft^2. Subtracting the mechanical and electrical space allotted in the basement, shafts, and penthouse, the system cost is about $140.47/ft^2.

LEED Version 3 Evaluation

The Leadership in Energy and Environmental Design (LEED®) program was created by the United States Green Building Council in order to help building owners and design teams realize the importance of energy efficient and environmentally friendly construction practices. LEED has two primary categories, Energy and Atmosphere (EA) and Indoor Environmental Quality (IEQ), which apply directly to the mechanical building systems. The LEED evaluation for this report focuses on the Energy and Atmosphere and Indoor Environmental Quality portions of the LEED rating system. The Integrated Sciences Building used LEED version 2.2 when evaluating the certification rating of the building, and had a primary goal of LEED Silver certification. However, as the building makes progress in construction, it has been realized that the building will likely receive LEED Gold certification.

Energy & Atmosphere

EA Prerequisite 1 – Fundamental Commissioning of Building Energy Systems

Intent – "To verify that the project's energy-related systems are installed, and calibrated to perform according to the owner's project requirements, basis of design and construction documents."

The Integrated Sciences Building has contracted an experienced private company to assist in commissioning of new mechanical and control systems. Inspections and documentation is to be turned over to the owner upon completion. The company works between the owner, the construction manager, and the subcontractors to ensure compliance with LEED requirements, and to ensure that the building is constructed to the applicable specifications and energy efficiency requirements.

EA Prerequisite 2 – Minimum Energy Performance

Intent – "To establish the minimum level of energy efficiency for the proposed building and systems to reduce environmental and economic impacts associated with excessive energy use."

The Integrated Sciences Building complies with ASHRAE Standard 90.1-2007 and energy modeling by a design engineering consultant shows that the building exceeds the minimum 10% energy improvement over the ASHRAE Standard 90.1-2007 Appendix G baseline building.

EA Prerequisite 3 – Fundamental Refrigerant Management

Intent – "To reduce stratospheric ozone depletion."

The refrigerant used in the Integrated Sciences Building electric centrifugal chillers are HFC 134a, which is allowable under this prerequisite because it is not a CFC-type refrigerant.

EA Credit 1 – Optimize Energy Performance (7 of 19)

Intent – "To achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use."

The energy modeling engineer's results show a 25% reduction in energy costs between the ASHRAE 90.1 baseline building and the proposed building configuration. This qualitative energy saving metric analysis in the LEED v3 rating scale gives the Integrated Sciences Building 7 of 19 possible points toward LEED certification.

EA Credit 2 – On-Site Renewable Energy (7 of 7)

Intent – "To encourage and recognize increasing levels of on-site renewable energy self-supply to reduce environmental and economic impacts associated with fossil fuel energy use."

The Integrated Sciences Building received the maximum possible amount of points for use of on-site renewable energy for the LEED v2.2 rating scale. In comparing that scale to the LEED v3 scale, the building receives all 7 possible points for EA Credit 2.

EA Credit 3 – Enhanced Commissioning (2 of 2)

Intent – "To begin the commissioning process early in the design process and execute additional activities after systems performance verification is completed."

As mentioned in the Fundamental Commissioning Prerequisite section above, the Integrated Sciences Building design and engineering team has contracted a separate commissioning consulting firm which specializing in helping the construction manager and owner with LEED-related commissioning. This includes training and operations manuals for the mechanical systems and direct reporting to the owner of commissioning design and review documents.

EA Credit 4 – Enhanced Refrigerant Management (0 of 2)

Intent – "To reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing direct contributions to climate change."

The procedure for determining qualification for EA Credit 4 is based on the satisfaction of a mathematical formula described below.

$\text{LCGWP} + \text{LCODP}\cdot 10^{15} \leq 100$

Where:

Lifetime Ozone Depletion Potentional (LCODP) = $[(\text{ODPr} \cdot (\text{Lr} \cdot \text{Life} + \text{Mr}) \cdot \text{Rc}]/\text{Life}$
(lb of CFC 11/Ton-Year)

Lifecycle Direct Global Warming Potential (LCGWP) = $[\text{GWPr} \cdot (\text{Lr} \cdot \text{Life} + \text{Mr}) \cdot \text{Rc}]/\text{Life}$
(lb CO_2/Ton-Year)

GWPr = Global Warming Potential of Refrigerant (0-12,000 lb CO_2/lbr)

ODPr = Ozone Depletion Potential of Refrigerant (0 to 0.2 lb CFC 11/lbr)

Lr = Refrigerant Leakage Rate (0.5% to 2.0%; default 2% unless otherwise demonstrated)

Mr = End-of-Life Refrigerant Loss (2% to 10%; default of 10% unless otherwise demonstrated)

Rc = Refrigerant Charge (0.5 to 5.0 lbs of refrigerant per ton of gross ARI rated cooling capacity)

Life = Equipment Life (10 years; default based on equipment type, unless otherwise demonstrated)

Tables 18-19 show the numbers used for the above variables.

HFC-134a Chiller	
Characteristic	Value
Lr	2.0%
Life	10 years
Mr	10%
Rc	3.2 lb_m/ton

Table 18 – Refrigerant Calculation values.

Refrigerant	ODP**	GWP**	LCGWP	LCODP	LCGWP + LCODP · 10^5
HFC-134a	0	1300	124.8	0	124.80*
** information from http://www.epa.gov/ozone/science/ods/classtwo.html *LEED Credit is YES if "LCGWP + LCODPe5" is ≤100					

Table 19 – LEED refrigerant calculation.

EA Credit 5 – Measurement and Verification *(3 of 3)*

Intent – “To provide for the ongoing accountability of building energy consumption over time.”

The Integrated Sciences Building mechanical systems are equipped with a data logging feature embedded in the Building Automatic System (BAS) which controls almost every aspect of the operation of mechanical and electrical systems within the facility. The owner has made a commitment to logging data and using that data to tune the building’s performance based on knowledge of how the systems work.

EA Credit 6 – Green Power *(2 of 2)*

Intent – "To encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis."

The energy model performed by the design engineer for EA Credit 1 provided an estimate of the actual electricity usage of the Integrated Sciences Building. The owner, in efforts to decrease its carbon footprint, has engaged in a contract with its electricity providers to purchase green energy credits in order to satisfy the Green Power portion of LEED v3. As a result, credit is awarded for EA Credit 6.

Indoor Environmental Quality

IEQ Prerequisite 1 – Minimum Indoor Air Quality Performance

Intent – "To establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants."

As investigated in great detail in Technical Report I, the Integrated Sciences Building complies with Sections 4 through 7 of ASHRAE Standard 62.1-2007. The building also meets CASE 1 as there are mechanically ventilated spaces that meet or exceed air flows as laid out in the ventilation rate procedure of ASHRAE 62.1-2007. Therefore, IEQ Prerequisite 1 was met.

IEQ Prerequisite 2 – Environmental Tobacco Smoke (ETS) Control

Intent – "To prevent or minimize exposure of building occupants, indoor surfaces and ventilation air distribution systems to environmental tobacco smoke (ETS)."

The Integrated Sciences Building does not allow any smoking inside the building whatsoever. All smoking locations outdoors are clearly labeled and are located such that smoke cannot enter the building as outlined in Section 5.18 of ASHRAE Standard 62.1-2007. In addition, design documents dictate that all of these areas exceed the minimum 25 feet of clearance from building entrances. Thus, IEQ Prerequisite 2 was achieved.

IEQ Credit 1 – Outdoor Air Delivery Monitoring *(0 of 1)*

Intent – "To provide capacity for ventilation system monitoring to help promote occupant comfort and well-being."

No CO_2 monitoring or Demand Control Ventilation (DCV) was specified for controlling air flow to the interior spaces of the Integrated Sciences Building. This LEED point was not pursued for the building and as such, no points were awarded.

IEQ Credit 2 – Increased Ventilation (0 of 1)

Intent – "To provide additional outdoor air ventilation to improve indoor air quality (IAQ) and promote occupant comfort, well-being and productivity."

Although some spaces within the Integrated Sciences Building do receive more supply air than required by ASHRAE 62.1-2007 due to building pressurization and infiltration concerns, this supply air cannot be guaranteed to be outdoor air during times when the economizer is not in use. Additionally, not all spaces have air flows that exceed requirements by 30%. This is especially true in the laboratory spaces where the minimum outdoor air flow rates are high based on the air changes required in the 100% outdoor air systems. Energy costs for conditioning this air in the summer or winter months would increase energy consumption of the building. Thus, no points were awarded for IEQ Credit 2.

IEQ Credit 3 - Construction Indoor Air Quality Management Plan

Intent – "To reduce indoor air quality (IAQ) problems resulting from construction or renovation to promote the comfort and well-being of construction workers and building occupants."

IEQ Credit 3.1 – During Construction (1 of 1)

During construction, the general contractor set forth specific rules for ensuring Indoor Air Quality (IAQ) during construction. These rules follows IEQ Credit 3.1 very closely, with prime emphasis on obtaining credit for this portion of the LEED v3 scale. This includes control measures set forth by the Sheet Metal and Air Conditioning National Contractors Association (SMACNA), on-site stored material protection, and MERV 8 filters and replacement guidelines set forth in ASHRAE Standard 52.2. Upon visiting the site when HVAC ducting was in the process of being installed, it was very evident that these procedures were being followed. All duct sections were sealed with clear plastic on any openings to prevent dust and debris from entering the system prior to installation.

IEQ Credit 3.2 – Before Occupancy (1 of 1)

Before the Integrated Sciences Building will be occupied, the "Flush-Out" method will be used to ensure proper removal of contaminants which are left over from the construction process. PATH 1 of the IEQ Credit 3.2 will be used. This method dictates that 14,000 cubic feet of outdoor air per square foot of floor area is supplied to the building while the interior building temperature is above 60°F and less than 60% relative humidity. These steps will be followed in order to achieve IEQ Credit 3.2.

IEQ Credit 4 – Low-Emitting Materials (4 of 4)

Intent – "To reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants."

The Integrated Sciences Building's mechanical systems specifications explicitly require that all adhesives and sealants used for ductwork and other mechanical systems must follow those requirements set forth in LEED v2.2 IEQ Credit 4. Similar language was also discovered within the architectural specifications for selection of any paint, flooring, or composite wood products. The owner's desire to achieve LEED certification played a major role in the selection of materials that follow the requirements for LEED-approval. Therefore, all four credits for IEQ Credit 4 were awarded.

IEQ Credit 5 – Indoor Chemical and Pollutant Source Control (0 of 1)

Intent – "To minimize building occupant exposure to potentially hazardous particulates and chemical pollutants."

The Integrated Sciences Building LEED scorecard does not include points for IEQ Credit 5. There are several requirements of this portion of the LEED rating system which includes a minimum of 10 feet of length for entryways that capture dirt and particulates. The atriums on the east and south sides of the buildings do not meet this criteria. Aside from this feature, the remainder of the requirements for this credit have been met, which means that a small modification during the architectural design phase may have gained the extra LEED point.

IEQ Credit 6 – Controllability of Systems [Lighting & Thermal Comfort] (0 of 2)

Intent – "To provide a high level of lighting system control by individual occupants or groups in multi-occupant spaces (e.g., classrooms and conference areas) and promote their productivity, comfort and well-being."

System controllability was not implemented to the degree of LEED IEQ Credit 6 compliance for the Integrated Sciences Building. Although lighting occupancy sensors were used for energy saving possibilities, they were not implemented in the minimum 90% of all spaces for this credit. Also, individual comfort controls were not provided for 50% of all occupants. Presumably, the owner did not want to enable occupants to change set points which could alter the energy consumption of the system.

IEQ Credit 7 – Thermal Comfort [Design and Verification] (2 of 2)

Intent – "To provide a comfortable thermal environment that promotes occupant productivity and well-being."

Design specifications for the Integrated Sciences Building were required to comply with ASHRAE Standard 55-2004 in establishing the interior set points for temperature and humidity. In a previous section of this report, these values are listed for each space for summer and winter months. All values follow the requirements. One point was therefore awarded for IEQ Credit 7.1 and therefore the prerequisite for IEQ Credit 7.2 was achieved. IEQ Credit 7.2 itself was achieved as surveys of thermal comfort are required to be performed. Since the building is still under constructed, the results are not listed in this report. However, points are awarded assuming the minimum requires are met, which includes a survey 6-18 months after occupancy with less and 20% of people dissatisfied with thermal comfort.

IEQ Credit 8 – Daylight and Views (0 of 2)

Intent – "To provide building occupants with a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building."

IEQ Credit 8.1 – Daylight and Views – Daylight

This credit was not met. The method of evaluation was a day lighting simulation with calculated illuminance values. Since the window area is much less than the maximum allowable in ASHRAE Standard 90.1, which was discussed in further detail in Technical Report I, it is no surprise that the day lighting does not meet the minimum criteria for LEED credit.

IEQ Credit 8.2 – Daylight and Views – Views

Similar to IEQ Credit 8.1, it is not unusual that the views in the building do not meet minimum LEED IEQ 8.2 criteria due to the more conservative approach on the amount of glazing on the exterior of the building. The Integrated Sciences Building is not a structure with huge expanses of exterior glass. This, no doubt, improves the energy efficiency of the temperature control systems within the building due to the higher thermal mass in the exterior walls, as well as the lack of heat gains through direct radiation though fenestrations.

Other LEED Consideration

Many LEED points are awarded for areas of engineering design other than mechanical systems, such as advanced commissioning. Appendix A shows a breakdown of points that are projected to be awarded according to the LEED analysis engineer-of-record for the Integrated Sciences Building Project. Note that this table does not follow the newest scale, LEED v3, which was used above. The engineer on the project evaluated the building with the LEED v2.2 scale. However, because this scale will be the one used to base any LEED certification on, it provides a good evaluation of the building.

Overall System Evaluation

One of the goals of the Integrated Sciences Building was to establish the owner, which in this case is an urban University organization, as a leader in sustainable construction and technology. There are many factors that play a role in determining the success of a building's "sustainability" and mechanical systems are major factor in that evaluation. In many cases, the LEED rating systems is used to quantify some of the sustainable features of a building. Whether or not that LEED is a good measure for determining sustainability can be a matter of opinion.

There are some features that immediately provide evidence of a responsible design that was intended to reduce energy consumption. One of the first that plays a major role in the building's performance is the choice of a VAV system. Although VAV systems are more expensive than a constant volume air system, they have proven to be effective in reducing energy consumption. For the types of occupancy in the Integrated Sciences Building, which includes many classrooms and offices, VAV systems are often used in new buildings for this reason. In the laboratory spaces, the need for high volumes of outside air to ensure air quality also made it easy to see how a VAV system could reduce the energy use of the building. Even a relatively minor change in air volume delivered to a space can change energy consumption a great deal, especially over the course of a year or the life of the building.

The type of energy used in the Integrated Sciences Building was another area which could make a huge impact on the sustainability of a project. Since the building has access to a district steam system, it removed the need for a boiler within the building. This can easily be seen as a cost-saving measure, but is often a more efficient use of fossil fuels than on sit combustion. Since larger steam plants operate more efficiently than small, locally-sized boilers, the access to district steam was a perfect opportunity to improve the mechanical design of the building.

One of the most impressive features of the Integrated Sciences Building is the Glycol Heat Recovery System which makes large strides in an effort to use energy which would otherwise be wasted. The simple concept of exchanging heat from exhaust air to incoming supply air, as well as heat from steam condensate, is projected to save a large portion of the energy cost of the building. As someone who is fairly inexperienced with building mechanical systems, it was very easy to see how a very simple system can be very effective.

The cost of initial installation of mechanical systems as well as the operating cost is also a very good way to gauge the success of a building design. The improvements made above the ASHRAE baseline building are project to save 25% of the annual energy costs of the building, according to the energy modeling engineer. Although this does not qualify the building for the most LEED points, it is a significant annual savings given that the building is predominantly a conventional VAV system with an extra heat recovery loop. The cost of the mechanical system is 23% of the total building cost, but when considering the amount of energy savings, is in line with the typical 15-20% of the total building cost which some engineers use as a rule of thumb for total system cost.

Overall, the building seems to have very simple systems which perform very well. The building is expected to reach LEED Gold certification, which may or may not render it a “success” in the eyes of some engineers. Points and ratings aside, it will be very challenging to come up with a design to improve the performance of the Integrated Sciences Building. Realizing that improving the building is a tall task, as well as some of the qualitative evaluations in this and previous technical reports, provides reason to render the building successful.

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Appendix A – LEED v2.2 Scorecard

Targeted	Not Pursued	LEED® Scorecard for Integrated Sciences Building	
10	4	Sustainable Sites	
•		SSP1	Construction Activity Pollution Prevention
1		SSC1	Site Selection
1		SSC2	Development Density & Community Connectivity
	1	SSC3	Brownfield Redevelopment
1		SSC4.1	Public Transportation Access
1		SSC4.2	Bicycle Storage & Changing Rooms
	1	SSC4.3	Low Emitting & Fuel Efficient Vehicles
1		SSC4.4	Parking Capacity
1		SSC5.1	Protect or Restore Habitat
1		SSC5.2	Maximize Open Space
	1	SSC6.1	SW Design - Quantity Control
1		SSC6.2	SW Design - Quality Control
1		SSC7.1	Heat Island Effect, Non-Roof
1		SSC7.2	Heat Island Effect, Roof
	1	SSC8	Light Pollution Reduction
4	1	Water Efficiency	
2		WEC1	Water Efficient Landscaping
	1	WEC2	Wastewater
2		WEC3	Water Use Reduction
9	8	Energy & Atmosphere	
•		EAP1	Fundamental Commissioning of Energy Systems
•		EAP2	Minimum Energy Performance
•		EAP3	Fundamental Refrigerant Management
6	4	EAC1	Optimize Energy Performance
	3	EAC2	On-Site Renewable Energy
1		EAC3	Enhanced Commissioning
	1	EAC4	Enhanced Refrigerant Management
1		EAC5	Measurement & Verification
1		EAC6	Green Power
7	6	Materials & Resources	
•		MRP1	Storage & Collection of Recyclables

	3	MRC1	Building Reuse
2		MRC2	Construction Waste Management
	2	MRC3	Materials Reuse
2		MRC4	Recycled Content Materials
2		MRC5	Regional Materials
	1	MRC6	Rapidly Renewable Materials
1		MRC7	Certified Wood
8	7	Indoor Environmental Quality	
•		EQP1	Minimum IAQ Performance
•		EQP2	Environmental Tobacco Smoke Control
	1	EQC1	Outdoor Air Delivery Monitoring
	1	EQC2	Increase Ventilation Effectiveness
1		EQC3.1	Construction IAQ - During Construction
1		EQC3.2	Construction IAQ - Before Occupancy
1		EQC4.1	Low-Emitting Adhesives & Sealants
1		EQC4.2	Low-Emitting Paints & Coatings
1		EQC4.3	Low-Emitting Carpets
1		EQC4.4	Low-Emitting Composite Wood and Agrifibre
	1	EQC5	Indoor Chemical & Pollutant Source Control
	1	EQC6.1	Controllability of Systems - Lighting
	1	EQC6.2	Controllability of Systems - Thermal Comfort
1		EQC7.1	Thermal Comfort - Design
1		EQC7.2	Thermal Comfort - Verification
	1	EQC8.1	Daylight 75% of Spaces
	1	EQC8.2	Daylight 90% of Spaces
5	0	Innovation & Design Process	
1		IDC1.1	Green Housekeeping
1		IDC1.2	Building Exterior & Hardscape Management
1		IDC1.3	Exemplary Performance - Water Efficiency
1		IDC1.4	Innovation & Design: Hydration Station
1		IDC2	LEED® Accredited Professional
43	26	Total Points	