Tech Report Three

Systems Existing Conditions Evaluation

Biobehavioral Health Building

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Tech Report Three

Executive Summary

The intent of this report is to summarize the function and design of the mechanical systems used within the Biobehavioral Health Building (BBH). This report also analyzes the overall operation and energy consumption of the building.

The mechanical systems of BBH are well designed with flexibility, comfort and efficiency in mind. A unique combination of a full variable air volume (VAV) air system and perimeter radiant heat system was used to effectively create a comfortable environment for students and faculty. The various building zones were divided amongst six air handling units. The six units are divided into the following zones: core offices, classrooms, south offices, north offices, core and conference.

The estimated cost of the mechanical system is $3,424,000 which is about 7% of the total building cost. This is approximately $36/SF. This low cost could be due to the overall simplicity of the system. Since the entire building is conditioned via campus supply loops, heat pumps, chillers, cooling towers and other equipment are not necessary.

The use of campus supplied utilities greatly simplified portions of the design and reclaimed potentially lost space due to extra mechanical equipment. One change that could improved the overall mechanical system efficiency is the use of heat recovery systems. Other small changes could also be incorporated into the design to further improve system efficiency, other ideas will be further investigated in the Thesis Proposal.

Results and conclusions from Tech Report One and Two are summarized throughout this report to draw conclusions about the mechanical system.

Existing Mechanical System Description

The main mechanical system is a variable air volume (VAV) system divided into six air handling units (AHU) to serve six different areas of the building. BBH is also equipped with fin tube heating around the perimeter for additional heating.

Mechanical Design Objectives

BBH was designed with Penn State's University-wide Environmental Stewardship Initiative in mind. The building was designed to meet the U.S. Green Building Council's (USGBC) LEED Green Building Rating System. The University desired the building to meet the requirements for LEED Silver.

To meet the requirements of Silver Certification the design team emphasized the following:

1. Energy Conservation
2. Natural Resource Conservation
3. Prevention of Environmental Degradation
4. Occupant's Health, Well-being and Comfort
5. Total Cost of Ownership

The design team focused on the following LEED credits:

1. Storm water Design: Quantity Control (SS Credit 6.1)
2. Water Use Reduction (WE Credit 3.1)
3. Optimized Energy Performance (EA Credit 1.1-1.6)
4. Enhanced Commissioning (EA Credit 3)
5. Enhanced Refrigerant Management (EA Credit 4)
6. Green Power (EA Credit 6)
7. Construction Waste Management (MR Credit 2.1 & 2.2)
8. Recycled Content (MR Credit 4.1)
9. Regional Materials (MR Credit 5.1 & 5.2)
10. Certified Wood (MR Credit 7)
11. Outdoor Air Delivery Monitoring (EQ Credit 1)
12. Construction IAQ Management Plan: During Construction and Before Occupancy (EQ Credit 3.1 & 3.2)
13. Low-Emitting Materials (EQ Credit 4.1-4.4)

14. Indoor Chemical and Pollutant Source Control (EQ Credit 5)

15. Controllability of Systems: Lighting (EQ Credit 6.1)

16. Thermal Comfort: Verification (EQ Credit 7.2)

17. LEED Accredited Professional (ID Credit 2)

The main HVAC systems consist of central variable air volume (VAV) air handling units located in the basement and penthouse. Generally, the air handling units were located as close to the zone(s) they serve to minimized unnecessary ductwork. Supply VAV terminals with individual thermostats are located in each space. A direct digital control (DDC) building automation system is used throughout the building. The DDC system will interface with the University's Office of Physical Plant to allow for building level control.

Energy Sources

Biobehavioral Health's energy sources consist of chilled water and steam from the campus supplied loops along with electricity. Electricity for the campus is supplied through five substations by Allegheny Power. Campus rates of chilled water, electricity and steam are shown below in Table 3.1.

Table 3.1: Energy Rates	
Energy Source	**Campus Rate**
Chilled Water ($/ton-hour)	0.22
Electricity ($/kWh)	0.09387
Steam ($/1000lbs)	24.59

Influence of Design

The main influence of the energy efficient design was Penn State's University-wide Environmental Stewardship Initiative.

Design Conditions

BBH is located in University Park, PA but weather data of Pittsburg, PA was used for the simulation while Erie, PA weather data was used for the design. The outdoor design conditions for Pittsburg were obtained from TMY2 weather data and can be seen in Table 3.2.

Indoor design conditions were obtained from Penn State Design intent documents and can be see in Table 3.3.

Table 3.2: Outdoor Design Conditions				
Season	Pittsburg, PA		Erie, PA	
	Dry Bulb (°F)	Wet Bulb (°F)	Dry Bulb (°F)	Wet Bulb (°F)
Summer	89.1	72.5	90	74
Winter	1.76	-	0	-

Table 3.3: Indoor Design Conditions				
Space		Dry Bulb (occupied)	Humidity	Dry Bulb (unoccupied)
Typical Space	Cooling	75	50%	85
	Heating	70	-	60
Server and Telecom Room	Cooling	72	50%	72
	Heating	-	-	-

Design Ventilation Requirements

A ventilation rate calculation from ASHRAE Standard 62.1 was performed to verify BBH's mechanical systems provide enough ventilation air to the building. Standard 62.1 looks at the outdoor air intake rates base on space types and their applications, it also considers the number of occupants and floor area of each space.

Table 3.4 below is a summary of the ventilation rates determined from Tech Report One, where a more detailed analysis of minimum ventilation rates can be found.

Table 3.4: Minimum Ventilation			
AHU	Max Occupied OA CFM	ASHRAE 62.1 OA CFM	Compliance (Y/N)
1 (Core Offices)	4500	3476	Y
2 (Classrooms)	2750	4112	N
3 (South Offices)	4750	993	Y
4 (North Offices)	3150	962	Y
5 (Core)	5000	2041	Y
6 (Conference)	2700	2075	Y

Six air handling units were analyzed, it was determined that all but one of the air handling units comply with the minimum ventilation specified by ASHRAE Standard 62.1-2007 as seen above in Table 3.4. A possible reason for this is due to the variation in occupancy values use for the classrooms (AHU-2). This could be due to the size of the space and occupancy density use. A reduced occupant density of 35 persons/1000sf was used in lieu of 150 persons/1000sf to more accurately model the approximately known occupancy of the space. An estimate of the occupancy of the lecture hall is to be around 250 persons.

Design Load Estimates

An energy model was created using DesignBuilder with EnergyPlus to simulate the annual energy consumption of BBH. A more detailed analysis of the energy model can be found in Tech Report Two.

Table 3.5: Modeled vs. Designed Heating and Cooling Loads		
System	**Load**	**SF Per Basis**
Cooling Modeled (Tons)	159	490 SF/ton
Cooling Designed (Tons)	178	438 SF/ton
Heating Modeled (kBTU/hr)	3379	23 SF/kBTU
Heating Designed (kBTU/hr)	1758	44 SF/kBTU
Modeled SA CFM	61395	0.787 CFM/SF
Design SA CFM	69900	0.896 CFM/SF

As shown in Table 3.5 above, the modeled cooling load is about 10% less than the designed cooling load. This resulted in 490 SF/ton (modeled load) compared to 438 SF/ton (designed load). Conversely, the modeled heating load is about 92% greater than the design heating load. This significant difference could be the result of variations in the assumptions made for each of the separate models, such as conductance values used for walls, roofs, slabs and windows. Other internal loads were neglected due to the lack of information and for simplification.

Design Energy Usage Estimate

Table 3.5 below shows the annual energy consumption of BBH broken down by component for comparison. BBH costs approximately $1.35/SF to operate annually.

Comparing the results to the Commercial Building Energy Consumption Survey (CBECS) 2003, BBH annually consumes 71 kBTU/SF compared to about 83 kBTU/SF for both average building size and building type.

Table 3.5: Annual Building Loads						
Source	**kBTU**	**kWh**	**Ton-hour**	**Lbs Steam (x1000)**	**Utility Rate**	**Cost ($/Year)**
Heating	2,894,906	848,448		2,425	24.59	$59,620
Cooling	671,831	196,902	55,986	-	0.22	$12,317
DHW	173,522	50,856	-	145	24.59	$3,574
Plug Load	899,970	263,766	-	-	0.09387	$24,760
Lighting	641,851	188,116	-	-	0.09387	$17,658
System Fans	71,053	20,824	-	-	0.09387	$1,955
System Pumps	238,355	69,858	-	-	0.09387	$6,558

Table 3.5: Annual Building Loads						
Source	kBTU	kWh	Ton-hour	Lbs Steam (x1000)	Utility Rate	Cost ($/Year)
Total	5,591,488	1,638,771	55,986	2,570	-	$126,441

Mechanical Equipment Summary

BBH is served by six air handling units which are all variable air volume (VAV) units. A condensed AHU schedule can be seen in Table 3.6 below. There are a total of 103 air terminal units connected to their respective air handling unit. There are backup split systems for the server room and main telecom room.

Table 3.6: Air Handling Unit Schedule			
Unit	Area Served	Design CFM	MIN OA (CFM)
ACF 1	Core Offices	16,500	1,470
ACF 2	Classrooms	9,500	2,400
ACF 3	South Offices	13,300	550
ACF 4	North Offices	7,100	360
ACF 5	Core	14,300	1,000
ACF 6	Conference	9,200	250

Mechanical System Cost

The estimated cost of the mechanical system is $3,424,000 which is about 7% of the total project cost. This is approximately $36/SF.

Mechanical Space Requirements

There are a total of three mechanical rooms. Air handling units were place to reduce the amount of unnecessary ductwork. Table 3.7 below shows the total space allotted for mechanical equipment. As shown in Table 3.7, about 9% of the building space is used for mechanical equipment.

Table 3.7: Mechanical Room Area	
Room	Area (SF)
M004	1,926
M021	533
Penthouse	5,018
Mechanical Shafts	560
Total	8,037
Total Building Area %	9%

System Operations and Schematics

A building automation system (BAS) is used throughout BBH to ensure proper control of chilled and hot water systems along with controlling all VAV units. The chilled and hot water loops are monitored to ensure proper pressure differential to properly condition the building.

Air-side Operations

BBH uses VAV systems to condition all its spaces. Each air handling unit contains a preheat coil and cooling coil along with mixed air, preheat and cooling coil discharge temperature sensors. Each VAV terminal unit receives airs from their associated AHU which is controlled by a direct digital control (DDC) control system. Each terminal unit is also supplied with hot water for reheat. All the air handling units are identical except for AHU-1 utilizes a relief fan while AHU2-6 use return fans as shown in Figures 3.3 and 3.4 below.

Water-side Operations

Hot Water System

Hot water is produced from two plate frame heat exchangers (HTX1, HTX 2) that are connected to the campus steam loops. Hot water is circulated through the building by two pumps with variable frequency drives (VFD) feeding the hot water supply (HWS) lines as shown below in Figure 3.1. The pumps are staged in a primary/standby configuration. Steam also feeds a shell and tube heat exchanger to provide domestic hot water (DHW).

Chilled Water System

Like the hot water system, chilled water is provided via campus chilled water loops. Chilled water is circulated to the AHU's by the chilled water supply (CHWS) lines by three pumps each with a VFD as shown in Figure 3.2 below. Two of the pumps are staged in a primary/standby configuration, the third pump is non-simultaneous with primary/secondary. This third pump feeds the secondary flow in the system which is mainly the fan coil units that serve the server and telecom rooms which required cooling year round.

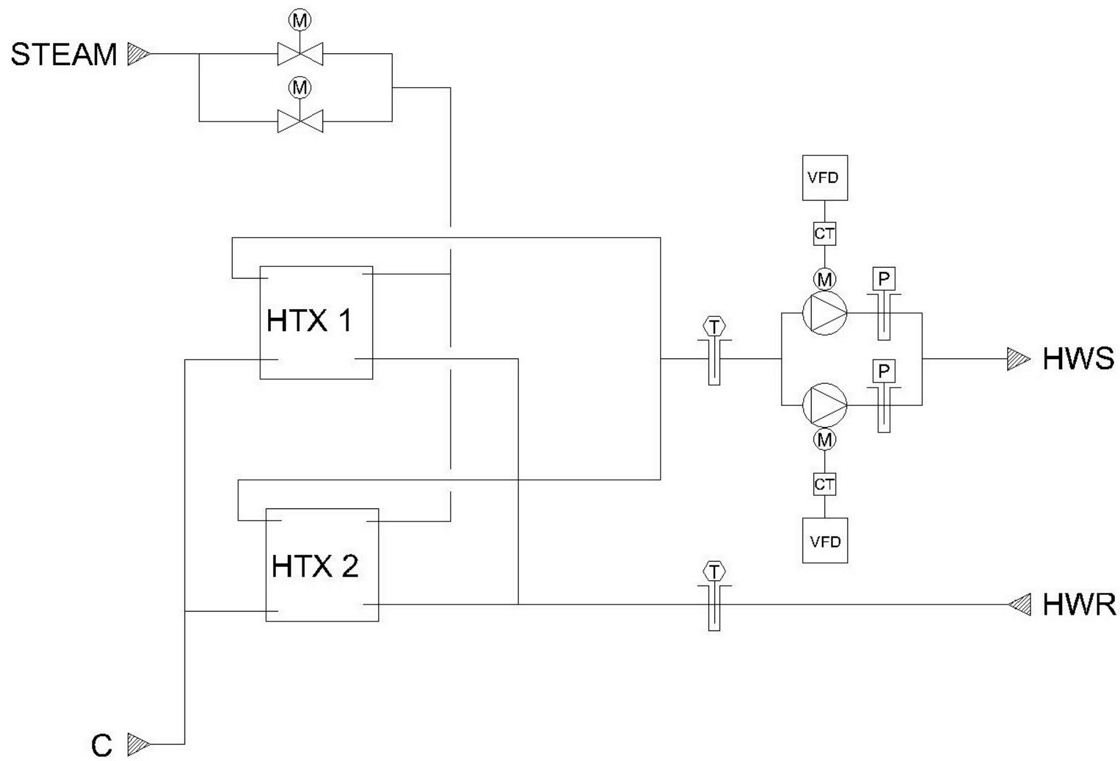

Figure 3.1: *Hot Water Schematic*

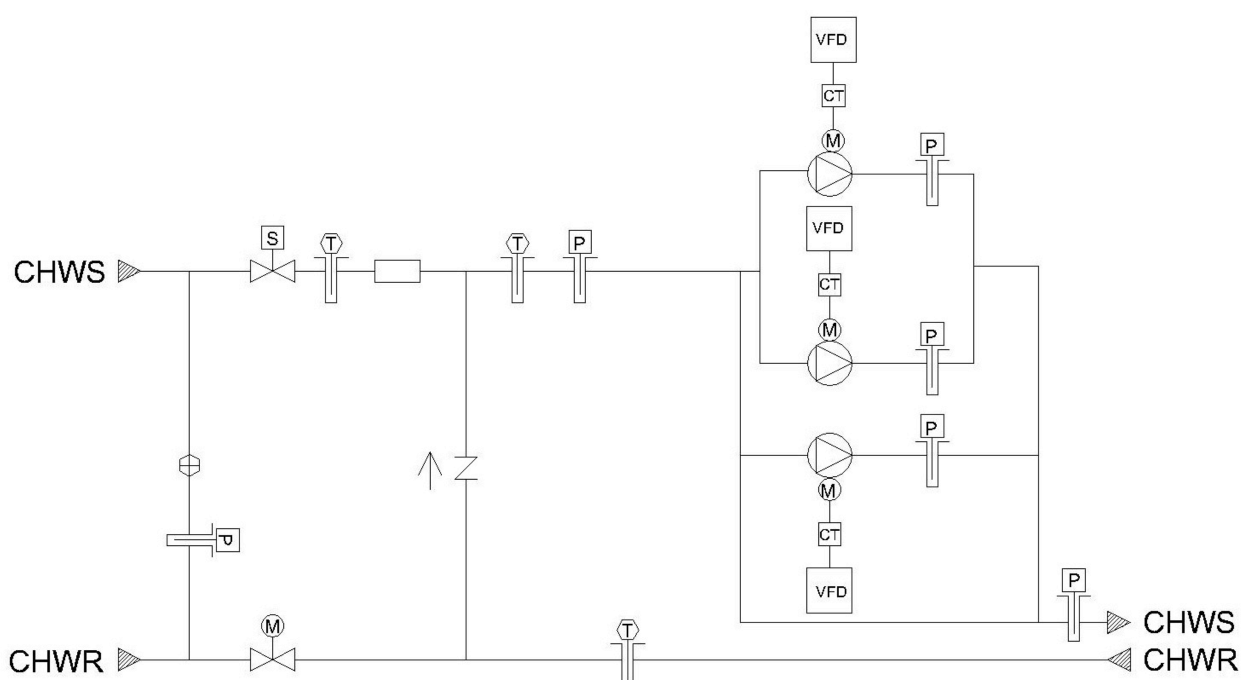

Figure 3.2: *Chilled Water Schematic*

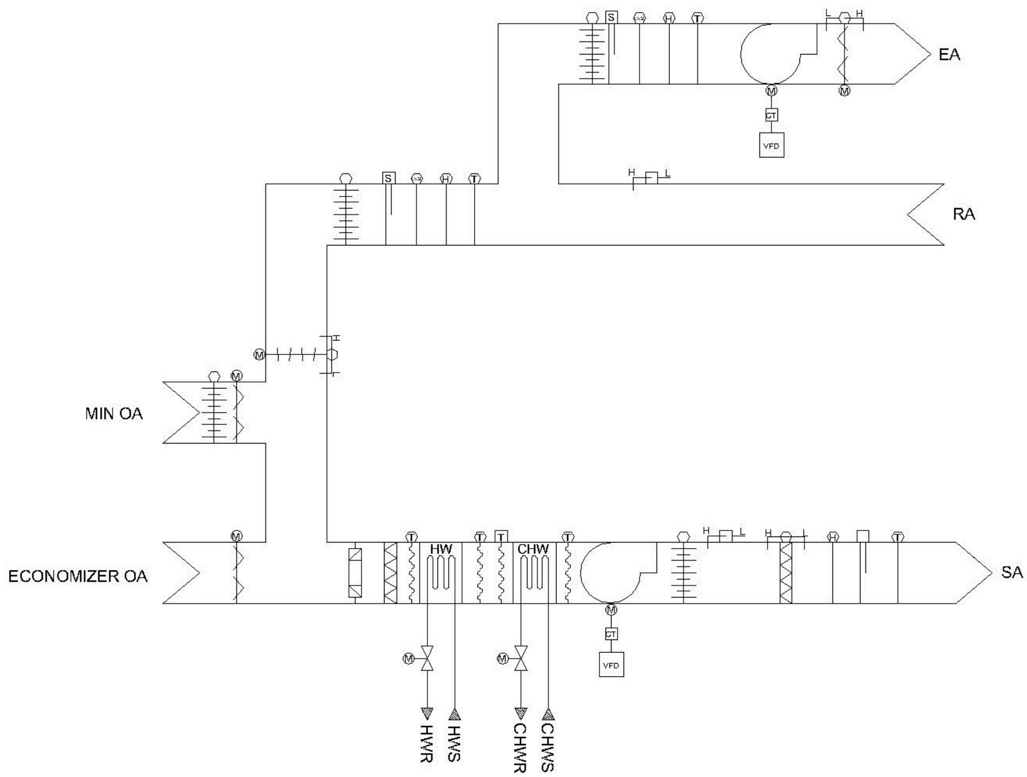

Figure 3.3: *AHU-1 (VAV with Relief Fan)*

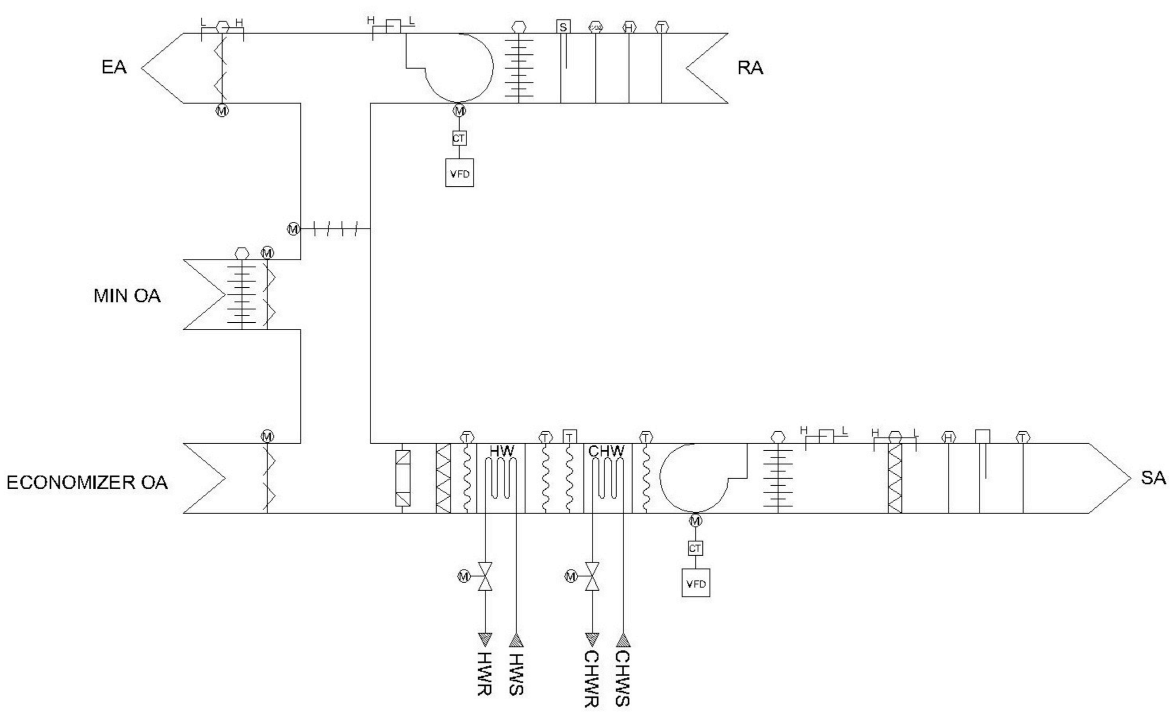

Figure 3.4: *AHU2-6 (VAV with Return Fan)*

LEED Analysis

A LEED assessment was completed for BBH using LEED-NC V2.2 by the designers. For this report the newer version of LEED was used, LEED 2009 for New Construction and Major Renovations. The tables below discuss the LEED credits that are be attempted and how the design team is approaching each credit.

There are numerous changes from V2.2 to LEED 2009 but most changes are simply assigned point values to various credits. A couple credits from V2.2 were condensed in LEED 2009 and increased in point value.

Sustainable Sites

Credit: Sustainable Sites	Action
Prerequisite 1: Construction Activity Pollution Prevention Intent: To reduce pollution from construction activities by controlling soil erosion, waterway sedimentation and airborne dust generation.	Stockpiles are protected to prevent water and wind erosion. A tire wash is used to help prevent sedimentation of storm sewers.
Credit 1: Site Selection Intent: To avoid the development of inappropriate sites and reduce the environmental impact from the location of a building on a site.	The site selected for BBH was previously a parking lot for Henderson North, Bridge and South. This complies with the requirements of site selection of LEED 2009.
Credit 2: Development Density and Community Connectivity Intent: To channel development to urban areas with existing infrastructure, protect greenfields and preserve habitat and natural resources.	BBH's site is located on a previously developed site, has pedestrian access, is within half a mile of at least 10 basic services and with half mile of a residential area.
Credit 4.1: Alternative Transportation - Public Transportation Access Intent: To reduce pollution and land development impacts from automobile use.	A bus stop is located within a quarter of a mile from BBH.
Credit 4.2: Alternative Transportation - Bicycle Storage and Changing Rooms Intent: To reduce pollution and land development impacts from automobile use.	Secure bicycle racks are provide around BBH and showers are provided for the occupants.

Credit: Sustainable Sites	Action
Credit 4.4: Alternative Transportation - Parking Capacity Intent: To reduce pollution and land development impacts from automobile use.	No new parking is provided.
Credit 5.2: Site Development - Maximize Open Space Intent: To promote biodiversity by providing a high ratio of open space to development footprint.	Green roofs are provided covering the majority of the roof and a large outdoor pedestrian-oriented hardscape is provide.
Credit 6.1: Stormwater Design - Quantity Control Intent: To limit disruption of natural hydrology by reducing impervious cover, increasing on-site infiltration, reducing or eliminating pollution from stormwater runoff and eliminating contaminates.	A cistern is provided that collects rainwater runoff from the roofs and is used to irrigate the landscape. A storm retention system was also installed to reduce the load on the storm system during heavy rain.
Credit 7.2: Heat Island Effect - Roof Intent: To reduce heat islands to minimize impacts on microclimates and human and wildlife habitats.	A vegetate roof will be installed and covers at least 50% of the roof area.

Water Efficiency

Credit: Water Efficiency	Action
Prerequisite 1: Water Use Reduction Intent: To increase water efficiency within building to reduce the burden on municipal water supply and wastewater systems.	The specifications call for low flow and sensor operated plumbing fixtures.
Credit 1: Water Efficient Landscaping Intent: To limit or eliminate the use of potable water or other natural surface or subsurface water resources available on or near the project site for landscape irrigation.	Storm water runoff from the roof is collected in an underground cistern. The collected water is used to irrigate the surrounding landscaping.

Energy and Atmosphere

Credit: Energy and Atmosphere	Action
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.	Facility Dynamics will be the commissioning agent and will check/test all major mechanical and electrical systems used throughout BBH.
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.	A whole building energy simulation was done using Carrier HAP v4.4 and the simulated proposed building had 28.5% improvement over the baseline.
Prerequisite 3: Fundamental Refrigerant Management Intent: To reduce stratospheric ozone depletion.	Building specifications call for refrigerations that comply with ASHRAE 15: Safety Standard for Refrigeration Systems.
Credit 1: Optimized Energy Performance Intent: To achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.	The proposed building was simulation and has an expected 28.5% improvement in energy efficiency compared to the baseline building.

Credit: Energy and Atmosphere	Action
Credit 3: Enhanced Commissioning Intent: To begin the commissioning process early in the design process and execute additional activities after systems performance verification is completed.	The commissioning process was utilized during the design phase of BBH.
Credit 4: Enhanced Refrigerant Management Intent: To reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing direct contributions to climate change.	None of the the AHU's use refrigerants. The back-up split system using R-410a which is a non-ozone depleting refrigerant. The fire suppression system does not use CFC, HCFC or halons as a suppressant.
Credit 6: Green Power Intent: To encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis.	Penn State currently purchases about 20% of its annual power demand from renewable sources.

Materials and Resources

Credit: Materials and Resources	Action
Prerequisite 1: Storage and Collection of Recyclables Intent: To facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills.	BBH will have recycle collection stations throughout the building.
Credit 2: Construction Waste Management Intent: To divert construction and demolition debris from disposal in landfills and incineration facilities. Redirect recyclable recovered resources back to the manufacturing process and reusable materials to appropriate sites.	All waste material is collected in two dumpsters on site and is later separated off site in Tyrone, PA. All materials that can be salvaged or recycled will be logged.
Credit 4: Recycled Content Intent: To increase demand for building products that incorporate recycled content materials, thereby reducing impacts resulting from extraction and processing of virgin materials	Recycled materials are used throughout the building.

Credit: Materials and Resources	Action
Credit 5: Regional Materials Intent: To increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the use of indigenous resources and reducing the environmental impacts resulting from transportation.	Regional materials and products are used throughout the project.
Credit 7: Certified Wood Intent: To encourage environmentally responsible forest management.	The majority of wood materials used in the building are certified with the Forest Stewardship Council's criteria.

Indoor Environmental Quality

Credit: Indoor Environmental Quality	Action
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.	All spaces are mechanically ventilated.
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).	Smoking is prohibited in all PSU buildings.
Credit 1: Outdoor Air Delivery Monitoring Intent: To provide capacity for ventilation system monitoring to help promote occupant comfort and well-being.	Co_2 sensors are provide throughout the building to ensure proper ventilation rates are being provided.

Credit: Indoor Environmental Quality	Action
Credit 3.1: Construction Indoor Air Quality Management Plan - During Construction Intent: To reduce indoor air quality (IAQ) problems resulting from construction or renovation and promote the comfort and well-being of construction workers and building occupants	Equipment is stored in a clean dry location. Duct openings are protected with plastic.
Credit 3.2: Construction Indoor Air Quality Management Plan - Before Occupancy 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.	Low VOC materials are used in the building thus reducing the need for an extensive “flush out”. Air filtration media will be changed if seen as necessary.
Credit 4.1: Low-Emitting Materials - Adhesives and Sealants 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.	Low VOC adhesives, sealants, paints, coatings, flooring materials and composite wood and agrifiber products are used extensively throughout the project. Each material is logged and submitted to LEED.
Credit 4.2: Low-Emitting Materials - Paints and Coatings Intent: To reduce the quantity of indoor contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.	
Credit 4.3: Low-Emitting Materials - Flooring Systems 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.	
Credit 4.4: Low-Emitting Materials - Composite Wood and Agrifiber Products Intent: To reduce and quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.	

Credit: Indoor Environmental Quality	Action
Credit 5: Indoor Chemical and Pollutant Source Control Intent: To minimize building occupant exposure to potentially hazardous particulates and chemical pollutants.	Low VOC materials are used extensively throughout the building reducing the need for extensive air purging and filtration.
Credit 6.1: Controllability of Systems - Lighting Intent: To provide a high level of lighting system control by individual occupants or groups in multi-occupant spaces and promote their productivity, comfort and well-being.	BBH uses occupancy sensors extensively throughout the building.
Credit 6.2: Controllability of Systems - Thermal Comfort Intent: To provide a high level of thermal comfort system control by individual occupants or groups in multi-occupant spaces and promote their productivity, comfort and well-being.	Individual controls are provided for the majority of building spaces. The controls allow occupants to enable adjustments to meet individual needs and preferences.
Credit 7.1: Thermal Comfort - Design Intent: To provide a comfortable thermal environment that promotes occupant productivity and well-being.	All spaces are design with independent temperature control to allow for maximum comfort and control.
Credit 7.2: Thermal Comfort - Verification Intent: To provide for the assessment of building occupant thermal comfort over time.	A thermal comfort survey of building occupants will conducted.

LEED Summary

Comparing LEED V2.2 to LEED 2009 BBH still has the ability to achieve a minimum of LEED Certification. The differences between the two versions are minimal resulting in a well ranked building.

Mechanical System Evaluation

Overall, the mechanical system of BBH is well designed with flexibility, comfort and efficiency in mind. A unique combination of a full VAV air system and perimeter radiant heat system was used to effectively create a comfortable environment for students and faculty. The various building zones/spaces were cleverly divided amongst six air handling units. The size units are divided into the following zones: core offices, classrooms, south offices, north offices, core and conference.

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Appendix

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