THE PENNSYLVANIA STATE UNIVERSITY
MILLENNIUM SCIENCE COMPLEX

MECHANICAL TECHNICAL REPORT ONE:
BUILDING/PLANT ENERGY ANALYSIS &
MECHANICAL SYSTEMS EXISTING CONDITIONS

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INTEGRATED PROJECT DELIVERY/ BUILDING INFORMATION MODELING SENIOR THESIS

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EXECUTIVE SUMMARY

The Millennium Science Complex is a four story, 275,600 SF square foot, LEED Gold Certified laboratory and office facility for the Life and Materials Sciences on The Pennsylvania State University, University Park campus. Located on the eastern end of campus at the corner of E. Pollack and Bigler Rd, the Millennium Science Complex will be the focus of the Integrated Project Delivery / Building Information Modeling Thesis (IPD/BIM Thesis). The building will house research facilities for the Material Sciences and Life Sciences departments. This report provides a preliminary investigation of the existing mechanical conditions and building/plant loads. From the basis of this analysis, we will be able to propose and investigate other design options in future reports.

The third floor of the Millennium Complex, roughly 45,000 SF, was selected as the focus of the building for this analysis and will be more strictly studied throughout the progression of our research. This floor provides a unique opportunity to study both life and material science laboratories, while incorporating common offices and conference rooms. The third floor is within the scope of a detailed analysis while providing complex interactions between all disciplines. While the whole building will be considered on a holistic level, actual calculations, coordination, and analyses in this report focus solely on the third floor.

The Millennium Science Complex's mechanical system assists the project with energy savings and result in a LEED Gold certification. An energy analysis of the third floor yielded 22% energy savings when compared to an ASHRAE Standard 90.1 model. Based on this comparison, the design of the entire building is expected to achieve 14% energy savings. The mechanical systems required for the varying uses of the Complex occupy approximately 15% of the buiding's total area. An estimation of the cost of the system was not attainable at the time of this report.

As part of the IPD/BIM Thesis, the mechanical reports will approach mechanical design with the purpose to create synergies with the architectural, lighting, electrical, environmental, and construction facets of design. By creating a more integrated design process, research should evolve a building design that improves the quality of its occupants' lives while decreasing the impact of the building on the environment.

This report begins the mechanical analyses that will be a part of the integrated design process. This paper develops the existing load, system, and energy conditions, so that future improvements may be tracked and compared. It begins with a general description of standards and design assumptions used to accurately model the functions and conditions of the Millennium Science Complex. This report goes on to create an analysis of the energy expended by the operation of the building along with its cost and environmental impacts. The major systems will be broken down for an understanding of their function. And finally, this report will provide insight into how Integrated Project Delivery and Building Information Modeling have been utilized to improve our analyses.

BUILDING OVERVIEW

The Millennium Science Complex is a four story laboratory facility that will combine the research of the Life Sciences and Material Sciences departments at Penn State under one roof. The building consists of stepping, green roofed, cantilevers that extend over campus streets, and will surely become one of the most recognizable buildings on the University Park campus.

The Millennium Science Complex also contains several outstanding sustainable features that will enable the project to attain LEED Golf certification. Green roofs cover the massive cantilevers and drain into a cistern to help reduce stormwater runoff. During construction over 90% of waste was diverted from disposal and over 10% of building materials were from recycled content. The complex mechanical system of the building employs an energy saving design that will reduce impact on the environment throughout the lifetime of the building.

A reliable and sustainable mechanical system is needed within the Millennium Science Complex In order to serve the varying occupants and uses. Laboratory spaces require consistent thermal and air quality conditions to ensure the accuracy of experiments. Laboratory AHUs contain energy recovery devices to offset energy costs associated with the higher indoor air quality requirements. Office spaces need to be designed for the comfort of their occupants with CO_2 measuring devices in dense areas to ensure indoor air quality standards are maintained.

The 4th floor of the building, which serves as the mechanical penthouse, and space in the basement of the building are used to connect into the existing campus chilled water and steam lines here at Penn State. The incoming high pressure steam is reduced to medium and low pressure steam for use in AHU coils, for process loads, and for the production of hot water through heat exchangers. Chilled water is pumped to the mechanical penthouse with the use of variable speed spilt case pumps.

DESIGN CONDITIONS

DESIGN INDOOR & OUTDOOR AIR CONDITIONS

For this project, the design indoor and outdoor air conditions for the Millennium Science Complex follow the instructions of Penn State's Office of Physical Plant (OPP). The outdoor air conditions can be compared to the recommended values from ASHRAE.

Table 1: ASHRAE Weather Data for University Park, PA

ASHRAE Altoona, PA	Summer Design Condition: Cooling 0.4%	Winter Design Condition: Heating 99.6%
Outside Air Dry Bulb (°F)	4.7	88.5
Outside Air Wet Bulb (°F)	-	72.0

Table 2: OPP Design Conditions

Area	Season	Indoor	Outdoor
Comfort Areas	Summer Winter	75°F DB, 50% RH 75°F DB, 50% RH	90°F DB, 74°F WB 0°F DB
Labs	Summer Winter	Lab specific	92°F DB, 74°F WB 0°F DB
Animal Holding	Summer Winter	64-79°F DB[1], 30-70% RH[1]	95°F DB, 75°F WB -10°F DB

1. *Reference "Guide for Care and Use of Laboratory Animals"*

Design for the labs and animal holding rooms are typically 100% dedicated outdoor air systems (DOAS). The change in the OPP design conditions reflects this. All supply temperatures to the lab and animal holding spaces should always remain constant.

In an effort to save energy, three set-points are typically used in the control of office spaces. "Occupied" will begin to heat spaces at 70°F and cool at 75°F. "Unoccupied" will heat at 60°F and cool at 85°F. "Holiday" will heat at 50°F and cool at 85°F.

It can be assumed that OPP is an experienced owner and has good reason to use values that are stricter than ASHRAE's design data for typical buildings in the same area.

DESIGN OCCUPANCY

At full capacity The Millennium Science Complex is designed to hold 2,898 occupants, not including the number of occupants under its first floor exterior atrium. Specifically, the third floor is designed for 735 persons. Given the office and laboratory functions of the floor, we will assume it to have 20% diversity for future calculations.

Table 3: Occupancy Per Floor

Floor	Occupants
Basement	462
Basement Mezzanine	48
First Floor	573
Second Floor	987
Third Floor	735
Penthouse	93
Total	2,898

The energy model used ASHRAE Standard 62.1 Table 6-1 as a basis for occupancy densities using the, "Space by Space Analysis." These values were reviewed and corrected to more accurately match the building's function and load. Each office containing at least three chairs was assumed to have 2 occupants. Each grad student cubicle was assumed to be an occupant. A diversity factor of 80% will also be added to account for periods off- peak occupancy.

Table 4: Excerpt from ASHRAE Standard 62.1 Table 6.1 Minimum Ventilation Rates in Breathing Zone

Occupancy Category	Occupant Density (#/1000 ft^2)
Lecture Classroom	65
Science Laboratories	25
Wood/Metal Shop	20
Computer Lab	25
Restaurant Dining Rooms	70
Break Rooms	25
Conference/Meeting	50
Office Space	5
Corridors	-
Storage Rooms	-

DESIGN LIGHTING & EQUIPMENT LOADS

Lighting power density loads were taken from ASHRAE Standard 90.1 Table 9.6.1 on a Space by Space Analysis. Each space was assigned a Common Space Type that best fit its function.

Internal equipment receptacle loads were assumed to match the default values supplied by Autodesk Revit MEP 2011 load calculation on a Space by Space Analysis. Given each type of space, a corresponding default load was applied.

Table 5: Lighting and Equipment Power Densities, using a Space by Space Method

Common Space Types	LPD , W/ft^2	EPD , W/ft^2
Office –Enclosed	1.1	1.5
Office – Open Plan	1.1	1.5
Conference/Meeting/Multipurpose	1.3	1.0
Classroom/Lecture/Training	1.4	1.0
Lounge/Recreation	1.2	0.5
Dining Area	0.9	0.5
Food Preparation	1.2	1.5
Laboratory	1.4	1.5
Restrooms	0.9	0.3
Corridor/Transition	0.5	0.3
Stairs - Active	0.6	0.3
Active Storage	0.8	0.3
Inactive Storage	0.3	0.3
Electrical/Mechanical	1.5	0.3
Post Office – Sorting Area	1.2	1.0

DESIGN SCHEDULES

As a university laboratory facility the Millennium Science Complex has a unique schedule of operations. Three sets of schedules were created to estimate the actual usage of the building. These schedules will help to accurately model the energy expenditure. Each hour was assigned a percentage of assumed peak occupancy. From the hours of 6am-8am and 6pm-8pm, it is assumed to be at 30% peak occupancy. For 8am-11am and 1pm-6pm, the building is assumed to be at peak occupancy during school hours. There is an assumed 85% occupancy for lunch hours, and no occupancy for a nighttime setting. Being a research facility, there is potential for it to be operational during the weekend, so a 50% occupancy rate was assigned to Saturday and Sunday. The schedules created were assumed since no operational schedules were provided and templates within Trane TRACE did not correlate with the anticipated usage of the building.

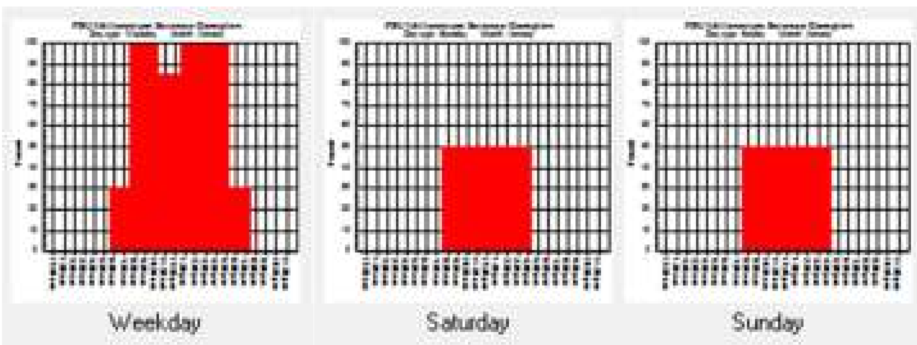


Figure 1: Millennium Science Complex Design Operation Schedules

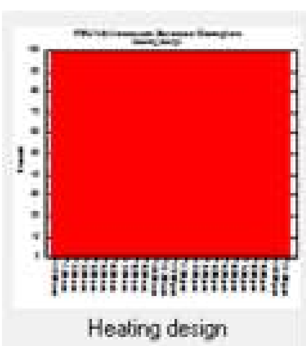


Figure 2: Millennium Science Complex Design Heating Schedule

BUILDING LOAD AND ENERGY MODELING

BASELINE ASHRAE 90.1 BUILDING MODEL

As explained in the executive summary, it was decided that only the 3rd floor would be the focus of detailed analysis. To provide a basis for future design considerations, the third floor was modeled in Trane Trace for a load and energy analysis. A model was created in accordance with ASHRAE 90.1 Baseline Standards, to provide the minimum energy efficiency requirements, using a space by space method. Adjustments to ASHRAE 90.1 were made to better fit the function of the Millennium Complex. Future models will be created to compare existing energy efficiencies and possible future savings.

Baseline Conditions –

- *Ventilation Rates* –ASHRAE Standard 62.1 Table 6-1 for Space by Space analysis
- *Occupant Densities* –ASHRAE Standard 62.1 Table 6-1 for Space by Space analysis. Offices adjusted for actual number of occupants.
  - Added an 80% diversity factor to account to fluctuations in occupancy.
  - A customized occupant and load schedule was created to simulate a university laboratory facility
- *Lighting Power Densities* –ASHRAE Standard 90.1 Table 9.6.1 for Space by Space analysis.
  - Added 10% diversity factor for lighting loads.
- *Equipment Loads* – Programmed values from Revit MEP 2011 Space Types for Space by Space analysis
- *Laboratory Air Changes* – Modeled with a design condition of 6 Air Changes Per Hour, based on general exhaust requirements
- *Building Envelope* – Modeled to minimum requirements according to Table 5.5-5 for Climate Zone 5A
- *HVAC System and Type* - Based on Table G3.1.1A – A non-residential building of greater than 150,000 sq. ft. using purchased heat will be modeled as System 7 – VAV with Reheat
  - Laboratories and Offices will be zoned separately
  - Laboratories will be served with 100% Dedicated Outdoor Air System with an outdoor air preconditioning energy recovery system
  - Offices will be supplied by a Variable Air Volume with Reheat System with 15% Outdoor Air
- *System Type* - Based on Table G3.1.1B – A System 7 will be modeled as a Packaged Rooftop VAV with Re-heat, with cooling supplied by chilled water and heating supplied by a hot water fossil fuel boiler
  - Heating will be supplied by campus purchased steam
  - Cooling will be supplied by campus chilled water
- *Weather Data* - 99.6% design days, 1% dry-bulb, 1% wet-bulb cooling temperatures must be used
- *Outdoor Ventilation Rates* - Must be the same for proposed and baseline building designs
- *Economizers* – A System 7 requires the use outdoor air economizers, with a high limit shut off at 70^{o}F
- *Energy Recovery* – Fan systems above 5000 cfm with 70% or greater minimum outside air requirements shall have an energy recovery system with at least 50% recovery effectiveness
- *Boilers* – For System 7, boilers shall be natural draft and use same fuel as proposed building
  - *Hot Water Temperature* – Modeled with 180 degree HWS, and 130 degree HWR
  - *Hot Water Reset* – Based on Outside Air Dry-Bulb Temperature, 180 degree at 20 degrees and below, and 150 degree at 50 degrees and above, ramped linearly
  - *Hot Water Pumps* – Only primary is required to be modeled. Will have Variable Frequency Drive

- *Chilled Water – For System 7*
    - *Chilled Water Temperature - Modeled with 44 degree CHWS, and 56 degree CHWR*
    - *Chilled Water Reset – Based on Outside Air Dry-Bulb Temperature, 44 degree at 80 degrees and above, 54 degree at 60 degrees and below, ramped linearly*
    - *Chilled Water Pumps – Shall model primary and secondary with Variable Frequency Drive*
- *Supply Air – Temperature will be reset based on zone demand with a temperature difference of 10 degrees under minimum loading*
- *VAV System – System 7 re-heat boxes will have a minimum flow of .4 cfm/ sq. ft. of floor area served*

Table 6: Baseline ASHRAE 90.1 Building Façade U-Value Conductivities

	U-Value ($BTU/hr\text{-}ft^2\text{-}F$)
Roof	0.048
Wall	0.064
Window	0.045
Slab	0.038

EXISTING DESIGN MODEL

An existing design model was created in Trane TRACE to compare the performance of the building to ASHRAE Standard 90.1. The goal of creating this model was to analyze the effectiveness of the existing design in TRACE and compare the results to the 14% energy savings outlined in the LEED credit report. The existing design model will also serve as a basis for future comparisons. As previously mentioned, the analysis only pertains to the 3rd floor of the Millennium Science Complex, so the comparison to the specified 14% energy savings cannot be considered highly accurate, but rather a preliminary estimation of savings.

A few key factors were improved upon in the existing design model which resulted in energy savings. A total enthalpy wheel was added to the lab AHUs. The ASHRAE Standard 90.1 model only utilized a coil loop to pre-condition outdoor air. The total enthalpy wheel, while increasing the overall system first cost, has been a proven method in reducing energy costs associated with 100% outdoor air systems. The fan types were also changed to model the variable frequency drives (VFDs) as outlined in the design documents. Variable frequency drives are another proven energy saving technology. The VFDs allow the AHUs to match the varying loads in the building instead of operating at full load constantly and in turn save energy. Finally, the enclosure was more accurately modeled and performed better than the baseline characteristics outlined by ASHRAE Standard 90.1.

As a result of the modifications to the ASHRAE Standard 90.1 model, the existing design showcased a total of 23% in annual energy cost savings. Errors in modeling can be attributed to the higher than expected savings percentage and will be investigated during later stages of this project.

More detailed breakdowns of the energy analysis can be found in Appendix C

Table 7: Existing Design Building Façade U-Value Conductivities

	U-Value (BTU/hr-ft^2-F)
Roof	0.157
Wall	0.040
Window	0.293
Slab	0.124

BUILDING LOAD SUMMARY

The Millennium Science Complex's building loads were simulated in Trane Trace. The following data shows the breakdown of the office and laboratory air handlers. In both cases, there is a significant reduction in peak loads and supply airflows. To check for accuracy, the loads were compared to a common rule of thumb of 1 cfm/ft^2. The office zone is nearly identical and the more energy intensive laboratory is within acceptable limits.

Table 8: Office Zone Load Summary

	Cooling (tons)	Heating (MBTUh)	Supply Airflow (cfm)	Outside Air Percentage	cfm/ft^2
Baseline 90.1	113.3	779.6	39,814	16.3	1.39
Existing Design	97.2	513.9	28,974	22.5	1.01

Table 9: Laboratory Zone Load Summary

	Cooling (tons)	Heating (MBTUh)	Supply Airflow (cfm)	Outside Air Percentage	cfm/ft^2
Baseline 90.1	295.8	3,151.4	34,078	100.0	2.19
Existing Design	217.7	2,409.2	25,588	100.0	1.64

UTILITY DATA

Utility Data was adapted from Penn State Office of Physical Plant (OPP) information available on their website. OPP's avoided costs information was input into our model and the following table summarizes the utilities used within the energy model and their respective rates

Table 10: Utility Information

Name of Utility	Cost ($)/Unit
Purchased Steam	9.85/1000 lbm (0.82/therm)
Purchased Chilled Water	0.22/ton-hr (1.83/therm)
Electric Consumption	0.07517/kWh
Electric On Peak	1.09/kW
Water (N/A in current model)	3.32/1000 gallons

EQUIPMENT ENERGY CONSUMPTION BREAKDOWN

The cooling system and its necessary equipment within the Millennium Science Complex account for more energy than any other category, as shown in Figures 3 and 4. In comparison to the ASHRAE 90.1 model, the cooling equipment still is the highest consumer of energy despite experiencing a 44% in chilled water energy reduction for the existing design, see Figure 4.

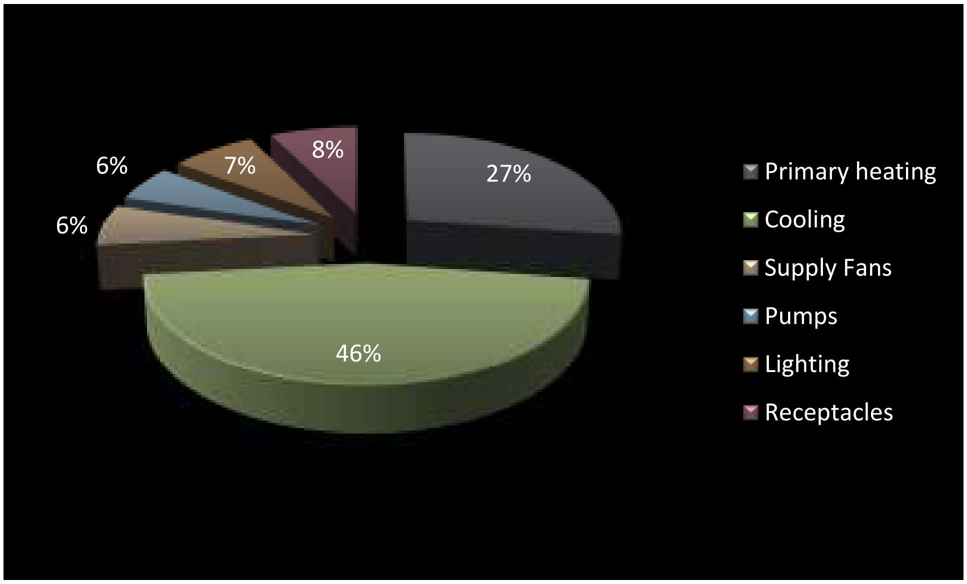


Figure 3: Equipment Energy Consumption: ASHRAE 90.1

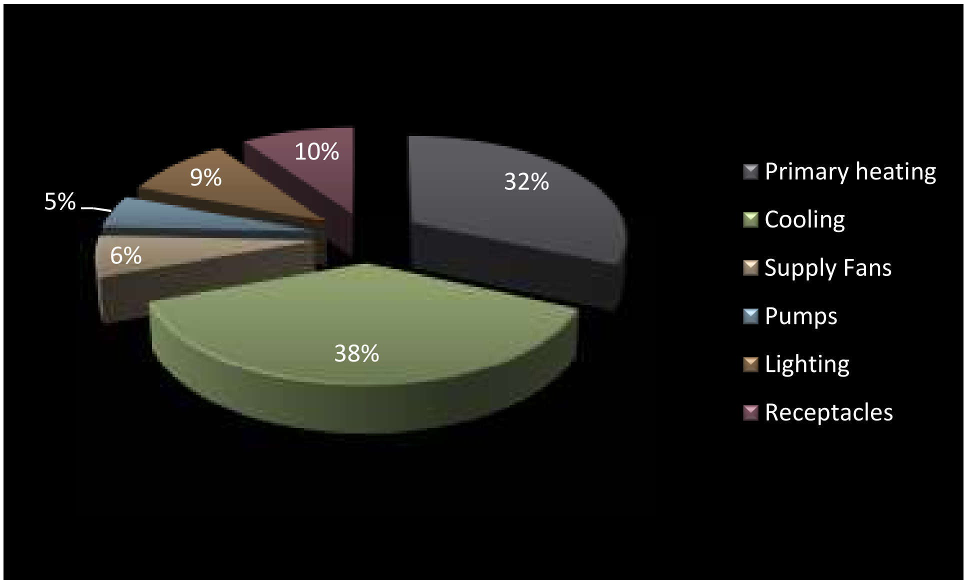


Figure 4: Equipment Energy Consumption: Existing Design

ANNUAL ENERGY CONSUMPTION & OPERATING COST ESTIMATE

The total annual cost estimated to operate the 3rd floor of the Millennium Science Complex came to $123,745 in the Existing Design model. This represents roughly 23% energy savings in comparison to the ASHRAE Standard 90.1 baseline model. The summer months, particularly July, represent the most costly months of the year due to the increase demand for chilled water for cooling the building. Process steam is still required during the summer months due to the process loads specific to the building.

Table 11: Summarized Annual Results

	ASHRAE 90.1	Existing Design	Percent Savings	Cost Savings
Electricity (kWh)	765,979	684,280	11%	$6,141
Purchased Chilled Water (therms)	45,039	28,705	44%	$29,891
Purchased Steam (therms)	26,694	24,119	9%	$2,111
Total Costs and Savings	$161,889	$123,745	**23%**	**$38,144**

Table 12: Comparison of Baseline and Existing Design Energy Intensities

	Baseline ASHRAE 90.1	Existing Design
Energy Intensity ($kBTU/ft^{2}$- yr)	221.2	172.2
Cost	$3.72/SF	$2.85/SF

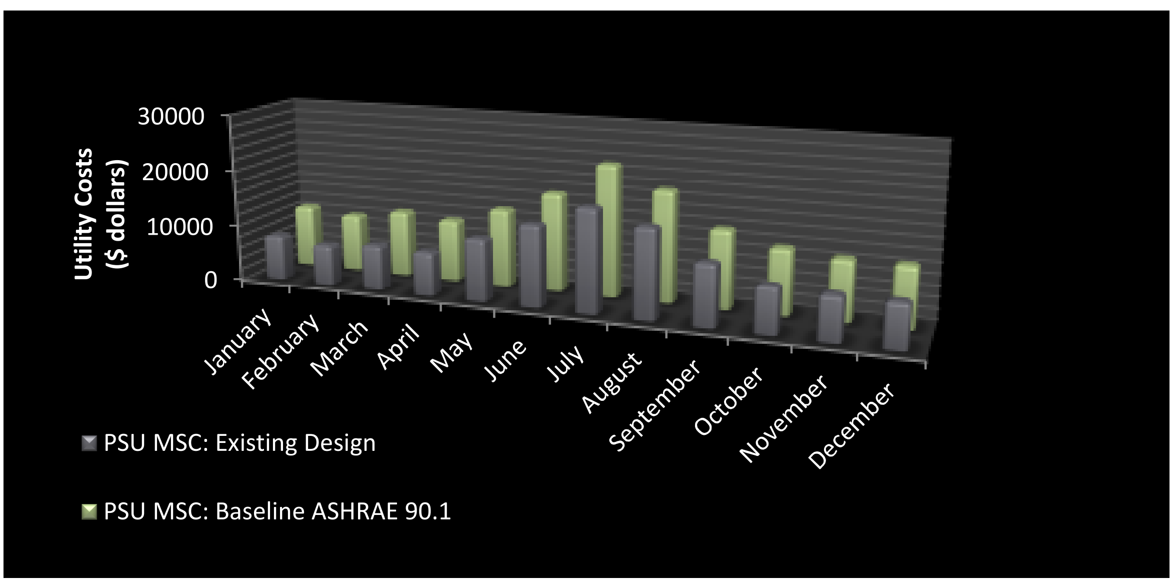


Figure 5: Comparison of Baseline and Existing Design Monthly Utility Costs

Table 13: Baseline ASHRAE 90.1 & Existing Model Monthly Energy Consumption & Costs

	Electricity (kWh)		Purchased Steam (therms)		Purchased Chilled Water (therms)	
	90.1	Design	90.1	Design	90.1	Design
Jan. Energy	62,633	53,682	3,856	3,720	1,629	351
Jan. Cost	$4,708	$4,035	$3,162	$3,051	$2,981	$642
Feb. Energy	56,759	48,539	3,624	3,487	1,463	288
Feb. Cost	$4,267	$3,649	$2,971	$2,859	$2,678	$526
Mar.	65,874	57,236	3,034	2,715	2,184	747
Mar. Cost	$4,952	$4,302	$2,488	$2,226	$3,996	$1,367
Apr. Energy	61,607	53,705	1,994	1,724	2,507	1,193
Apr. Cost	$4,631	$4,037	$1,635	$1,414	$4,588	$2,182
May Energy	66,840	60,696	959	869	4,187	3,060
May Cost	$5,024	$4,562	$786	$713	$7,663	$5,600
Jun. Energy	66,191	62,053	1,239	989	6,091	4,745
Jun. Cost	$4,976	$4,665	$1,016	$811	$11,146	$8,682
Jul. Energy	65,824	62,375	1,602	1,280	9,260	7,271
Jul. Cost	$4,948	$4,689	$1,318	$1,050	$16,946	$13,305
Aug, Energy	68,852	64,321	1,442	1,164	6,961	5,358
Aug. Cost	$5,176	$4,835	$1,182	$954	$12,739	$9,805
Sep. Energy	63,380	56,988	973	860	4,378	3,135
Sep. Cost	$4,764	$4,284	$798	$705	$8,012	$5,738
Oct. Energy	64,895	57,109	1,870	1,660	2,610	1,313
Oct. Cost	$4,878	$4,293	$1,534	$1,362	$4,777	$2,403
Nov. Energy	61,832	54,547	2,451	2,203	2,122	846
Nov. Cost	$4,648	$4,100	$2,010	$1,806	$3,884	$1,549
Dec. Energy	61,292	53,029	3,645	3,446	1,646	399
Dec. Cost	$4,607	$3,986	$2,989	$2,826	$3,013	$730

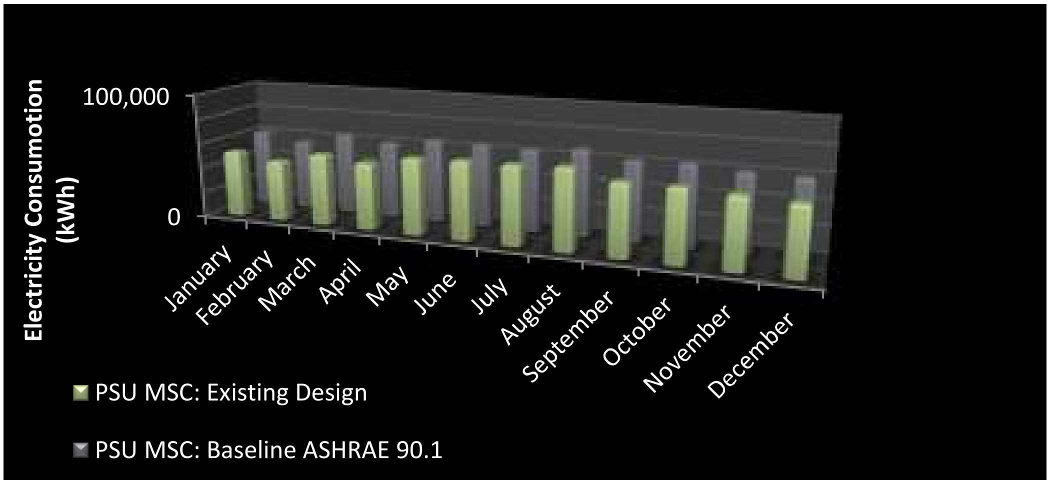


Figure 6: Comparison of Baseline and Existing Design Monthly Electricity Consumption

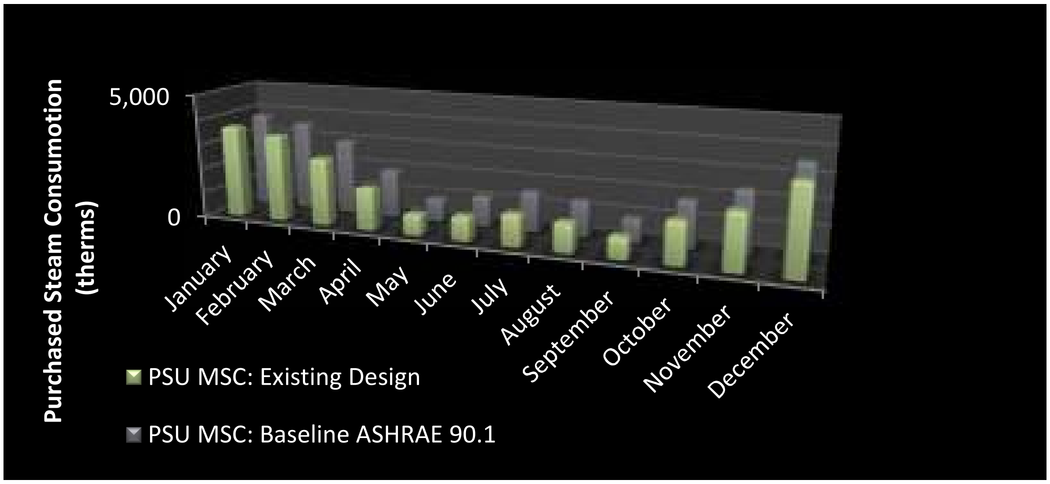


Figure 7: Comparison of Baseline and Existing Design Monthly Purchased Steam Consumption

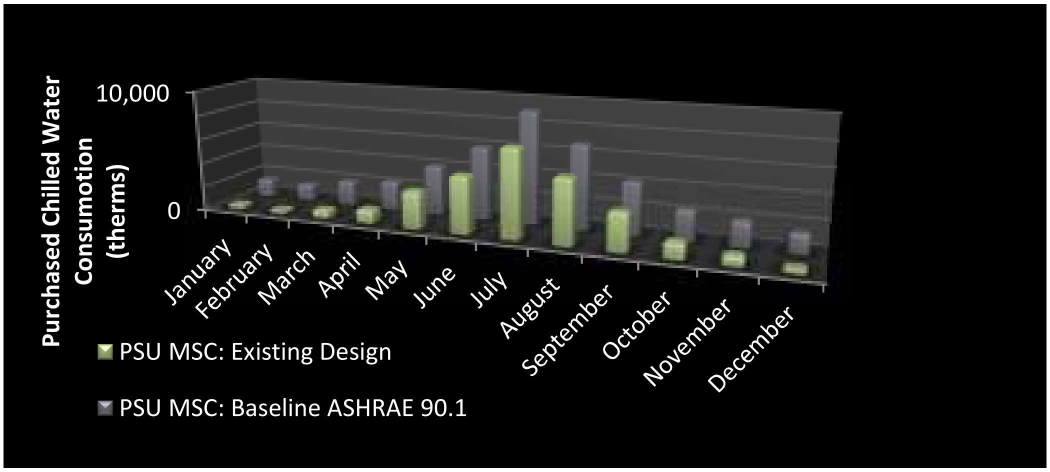


Figure 8: Comparison of Baseline and Existing Design Monthly Purchased Chilled Water Consumption

BUILDING EMISSIONS FOOTPRINT

The building emissions footprint of Penn State's Millennium Science Complex was analyzed using the total source energy consumption data calculated from Trane TRACE. The third floor was only modeled in TRACE due to time constraints. The third floor comprises roughly 45,000 SF of the 276,000 SF in the building. A comparison was done between the ASHRAE 90.1 Standard and the existing building conditions.

Table 14: Comparison of emission rates from Trane TRACE

	ASHRAE 90.1 Standard Emissions	Existing Design
Total Building Energy (Btu/ft^2-yr)	221,194	172,158
Total Source Energy (Btu/ft^2-yr)	335,995	280,932
CO_2 (lbm/yr)	3,487,813	2,714,609
SO_2 (gm/yr)	26,966	20,988
NO_X (gm/yr)	5,420	4,219

In comparison, an emissions analysis was performed using data obtained from National Renewable Energy Laboratory's technical report titled, "Source Energy and Emission Factors for Energy Use in Buildings." Factors for the amount of pollutant produced were taken from the Eastern United States data. The multiplier for the source energy factors is 2.528, assuming the use of fossil fuel energy. It is important to remember that Penn State purchases green power to offset emissions however that was not factored into these calculations.

Table 15: Comparison of emission rates from NREL

Pollutant	Lb produced per kWh delivered	90.1 Model Emissions (lbs)	Existing Design Model Emissions (lbs)
CO_{2e}	1.74	3,369,327	3,009,956
CO_2	1.64	3,175,688	2,836,970
Solid Waste	0.0205	39,696	35,462
SO_x	0.000857	1,659.5	1,482.5
NO_x	0.000300	580.9	519.0
CH_4	0.000359	695.2	621.0
CO	0.0000854	165.4	147.7
TNMOC	0.00000726	14.1	12.6
N_2O	0.00000387	7.5	6.7
PM10	0.00000926	17.9	16.0
Lead	0.0000000139	0.0269	0.0240
Mercury	0.00000000336	0.0065	0.0058

MECHANICAL SYSTEM EXISTING CONDITIONS OVERVIEW

SYSTEM OPERATION OVERVIEW

AIR SIDE

As shown in Figure 9, the airside system for The Millennium Science Complex utilizes a VAV system where each terminal unit is supplied with air from AHUs located in the mechanical penthouse. The air is supplied to the spaces through ceiling mounted low velocity radial diffusers to maintain room temperature setpoint. The air return is also through the ceiling plenum to the return air duct riser. CO_2 sensors are located in both the return air and outside air ducts on each floor to maintain the concentration level of 470 ppm of CO_2.

For the non-lab spaces the supply air is provide by three VAV AHUs, with 33,000 cfm capacity each. The VAV boxes are controlled by wall mounted temperature sensors to maintain a fixed temperature of 75°F. The north perimeter offices are serviced with hot water coils, which are the main heating source, for the VAV boxes. In decreasing loads, the static pressure sensor in the longest duct run controls the variable frequency drive for the supply fans. The non-laboratory AHUs utilize outdoor air economizer to save energy since they are not a dedicated outdoor air system. During the economizer mode, the return fan is capable of returning total air capacity and releases to the louvered penthouse. This is due to the supply fans interlocked to the return fans.

The animal care facility (vivarium) is serviced by two 25,000 cfm AHUs with 95% efficient air filters. The AHUs are 100% dedicated outdoor air systems that provide variable air volume to the spaces. To ensure operating capacity for the animal holding rooms and animal care facility, the AHUs were sized for 100% of maximum block airflow demand and are connected to standby power. The supply and exhaust air volumes are controlled by airflow control valves via the Laboratory Airflow Control System. General exhaust is removed through the ceiling inlet located over the bio-safety cabinet. The facility is exhausted with a dedicated exhaust system to two fans located on the roof. The exhaust system consists of manifold fume hood exhausts and the general room exhaust. Figure 9 shows a simplified exhaust riser diagram for the Millennium Science Complex.

The clean room is serviced by one dedicated AHU that is a DOAS system. It is designed to lower the humidity levels to 45% RH, which is required for pressurization and makeup air. The building's main supply air duct is routed to the clean room and capped for future fitout. In order to maintain proper indoor air quality, the clean room has a separate toxic exhaust fan and the main toxic exhaust system is routed to the clean room area and capped for future fitout. General exhaust from the room is routed to the main building general lab exhaust system.

Five 50,000 cfm DOAS AHUs provide supply air to the laboratories located in the Millennium Science Complex. The AHUs provide 100% of system capacity and are connected to standby power. In case of power loss, only one AHU will operate. To utilize energy, each unit includes an enthalpy heat recovery wheel and integral exhaust fan to operate concurrently with the supply. Energy is transferred from the lab general exhaust system and not the fume hood exhaust to ensure proper indoor air quality so that the incoming outdoor air does not get contaminated. Exhaust air is removed from the spaces with fume hoods, process point exhausts, and general exhaust registers. The fume hood and vivarium exhaust fans are equipped with run around energy recovery coils that circulate glycol with two pumps to the preheat coils in the AHF AHUs, clean room AHU, and quiet lab AHU. The supply and exhaust airflow are controlled by the Laboratory Airflow Control System. Phoenix venture valves are used to ensure proper ventilation and pressurization since the supply air valve is interlocked to the room general exhaust and fume hood exhaust.

WATER SIDE

CHILLED WATER:

The Millennium Science Complex chilled water is serviced from the PSU campus central plant. Chilled water is pumped into the northeast corner of the building into the ground level mechanical room. Four variable speed horizontal split case chilled water pumps in a manifold configuration, where one is used as a standby, pump the chilled water to the AHUs located in the mechanical penthouse on the fourth floor. Figure 10 shows a simplified diagram illustrating the chilled water layout. The chilled water is pumped to the penthouse and is circulated throughout the floors to the VAV boxes to service the cooling coils. A chilled water control valve modulates under varying load in the VAV to maintain a fixed coil discharge temperature for each zone. To maintain minimum flow throughout the system during very low flow conditions, each cooling coil has two way valves and a main differential pressure bypass. For partial load conditions, one low flow pump is provided in order to save energy. In case the pump fails a pump bypass line is provided with an automatic control valve to ensure system reliability.

The chilled water is pumped to two plate and frame heat exchangers before it reaches the mechanical penthouse, as shown in Figure 10, to service the secondary condenser water cooling. This is dedicated for process cooling of equipment and supplemental loads in the building to serve cold rooms and environmental rooms. The process cooling system flows past an expansion tank and through two variable speed drive circulation pumps in the basement mechanical room. Both the heat exchangers and circulation pumps were designed for redundancy to provide 100% backup. The pumps are connected to standby power to ensure flow upon power failure. The chilled water is also connected to standby power to provide cooling for the animal care facility (vivarium) AHU and one main lab penthouse AHU. Chilled water is to be redirected to these two AHUs from the cooling coil loop control valves upon power failure.

HOT WATER:

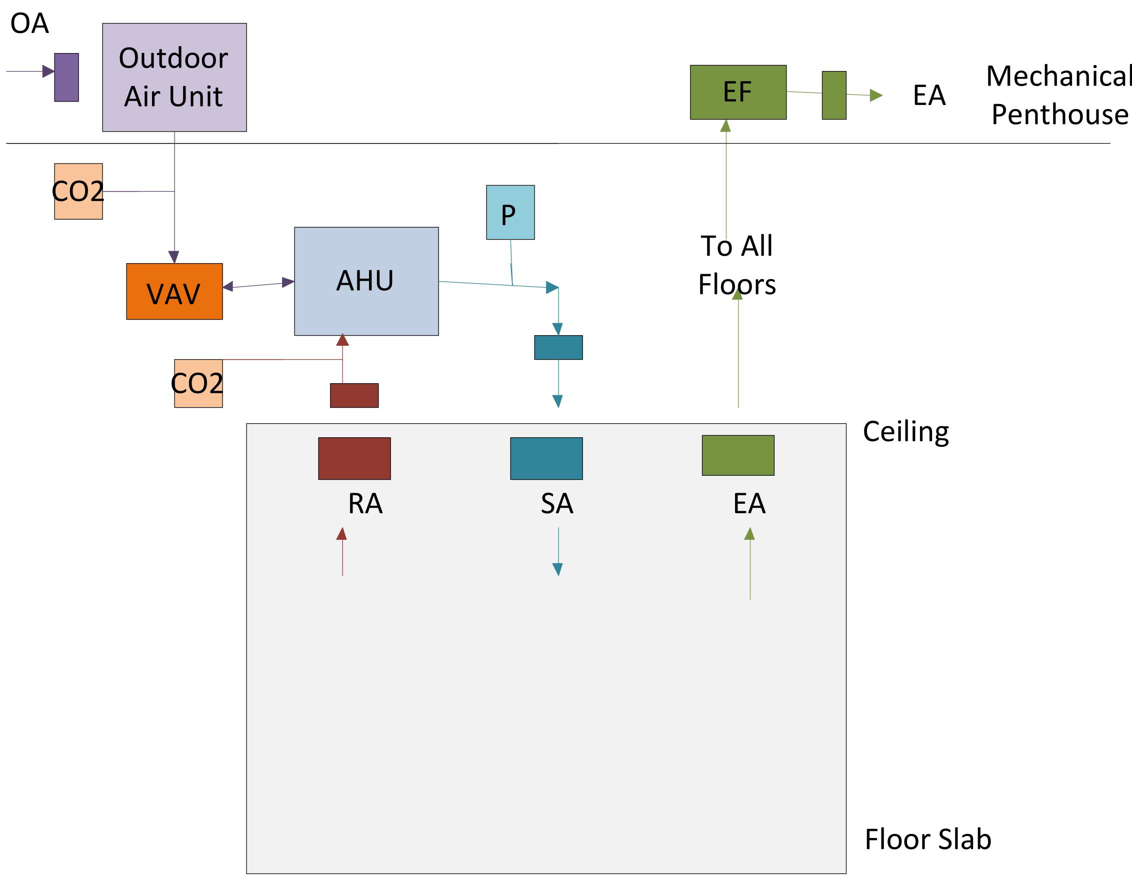
High pressure steam at 140 psig is the building's heating source and is supplied from the PSU campus boiler plant. The steam enters the northeast corner of the building into the ground mechanical room and flows to the pressure reducing station. At the PRV station, the high pressure steam is reduced to medium pressure at 60 psig with one pressure reducing valve, as shown in Figure 11. The medium pressure steam is used for equipment throughout the building, such as laboratory sterilization and domestic hot water heat exchangers. From the PRV station the MPS flows through three hot water heaters and then to three clean steam generators in the mechanical penthouse. The medium pressure condensate is collect then returns to a pump in the basement. Clean steam from the steam generators is fed to each laboratory AHU to provide the required lab humidity with clean filtered water. Medium pressure process steam at 85 psig is supplied to the vivarium and laboratories to serve glass washers, cage washers, sterilizers, and autoclaves.

At the PRV station, the high pressure steam is also reduced from 140 psig to 15 psig using two pressure reducing valves for low pressure steam. Low pressure steam is used for most of the mechanical equipment in the building such as: reheat and preheat coils at the AHUs, humidification and plate and frame hot water heat exchangers for perimeter heating elements, and terminal device reheat coils. From the PRV station, as shown in Figure 11, LPS flows to two redundant plate and frame steam to hot water heat exchangers to serve the lab and office reheat coils at air terminal devices. Two pumps placed in parallel circulate the hot water to the reheat coils. Two plate and frame steam to hot water heat exchangers with two inline pumps also serve the variable flow *perimeter finned tube elements in areas where the glass height is greater than 11 feet high, such as office spaces, conference rooms, and laboratories.*

Localized compressed air powered condensate pumps pump the steam condensate from the mechanical penthouse back to the ground level mechanical room. The condensate is then pumped back to the main campus boiler plant.

EXISTING SYSTEMS SCHEMATIC DRAWINGS

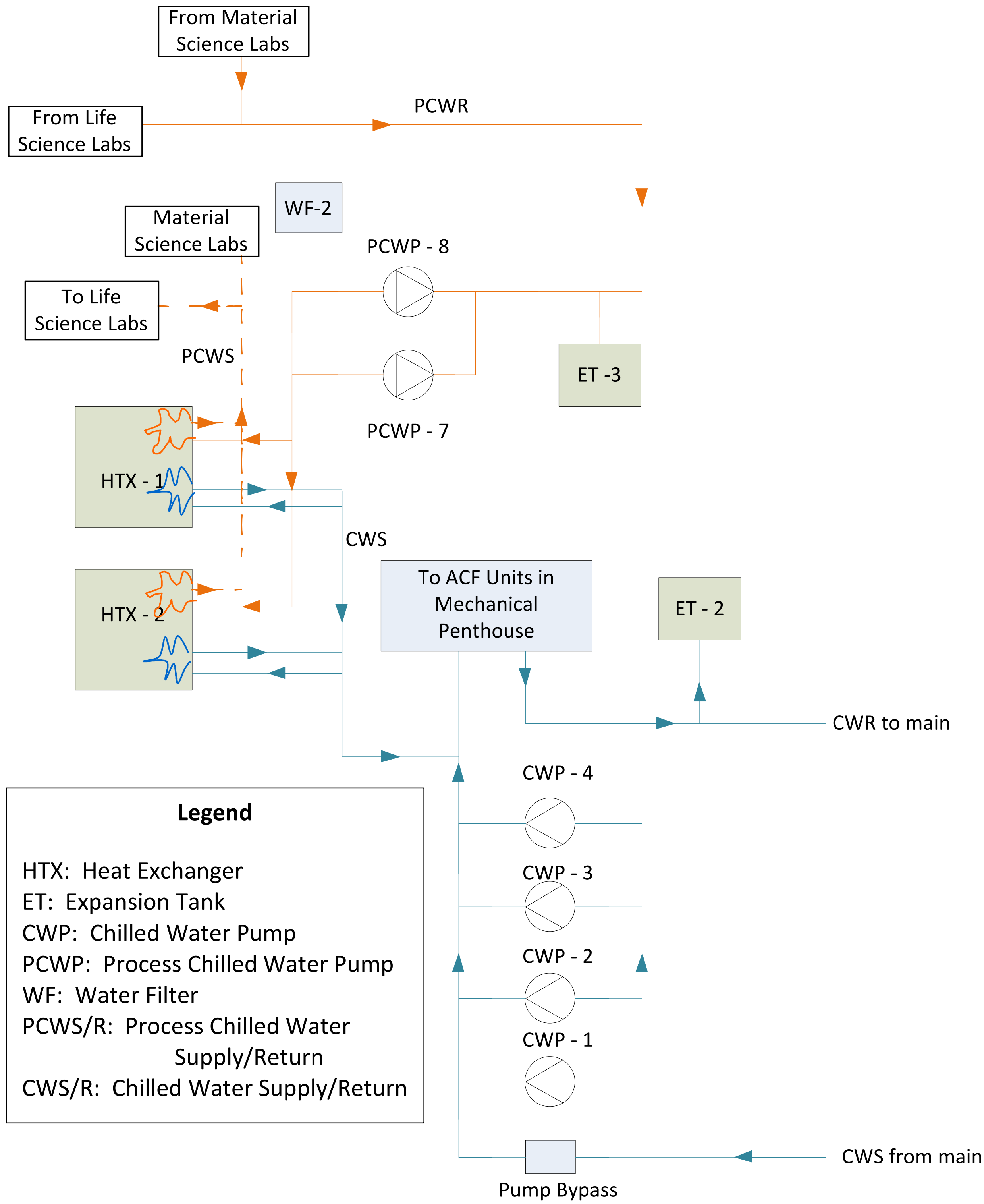
Figure 9: Typical Airside Diagram for Spaces



Legend

RA: Return Air
SA: Supply Air
EA: Exhaust Air
OA: Outside Air
CO_2: Carbon Dioxide Sensor
VAV: Variable Air Volume Box
EF: Exhaust Fan
P: Static Pressure Sensor

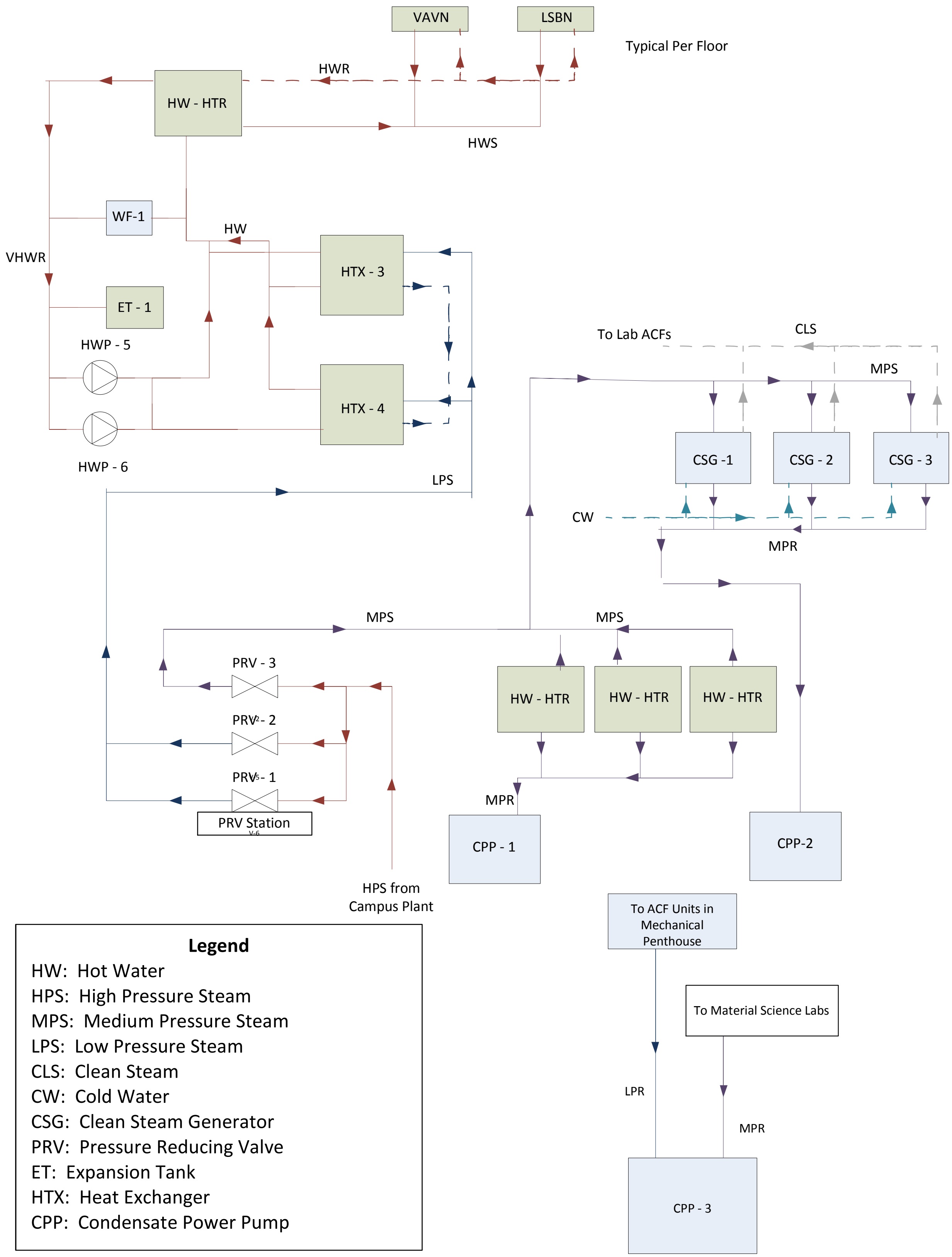
Figure 10: Chilled Water Flow Diagram



Legend

HTX: Heat Exchanger
ET: Expansion Tank
CWP: Chilled Water Pump
PCWP: Process Chilled Water Pump
WF: Water Filter
PCWS/R: Process Chilled Water Supply/Return
CWS/R: Chilled Water Supply/Return

Figure 11: Hot Water Flow Diagram



SUMMARIZATION OF MAJOR MECHANICAL EQUIPMENT

Table 16: Major Mechanical Equipment-Pumps

Designation	Service	Location	Flow Rate (gpm)	Total Pump Head (ft)	RPM	Pump Type
CWP-1	Chilled Water	Basement Mezzanine	2780	150	1800	Horizontal Split
CWP-2	Chilled Water	Basement Mezzanine	2780	150	1800	Horizontal Split
CWP-3 (standby)	Chilled Water	Basement Mezzanine	2780	150	1800	Horizontal Split
CWP-4 (low flow)	Chilled Water	Basement Mezzanine	800	60	1800	Horizontal Split
HWP-5	Hot Water Heating	First Floor	930	100	1800	Vertical In-line
HWP-6	Process Cooling Water	First Floor	930	100	1800	Vertical In-line
PCWP-7	Process Cooling Water	First Floor	600	100	1800	Vertical In-line
PCWP-8 (standby)	Radiant Cooling Water-Quiet Labs	First Floor	600	100	1800	Vertical In-line
CWP-9	Radiant Cooling Water-Quiet Labs	Basement	75	25	1800	Vertical In-line
CWP-10 (standby)	Radiant Cooling Water-Quiet Labs	Basement	75	25	1800	Vertical In-line
GWP-11	Glycol Heating/Cooling Run-Around Coil	Mechanical Penthouse	775	75	1800	Vertical In-line
GWP-12	Glycol Heating/Cooling Run-Around Coil	Mechanical Penthouse	775	75	1800	Vertical In-line
GWP-13	Snow Melt System	First Floor	25	85	3500	End Suction

Table 17: Major Mechanical Equipment- AHUs

Designation	Service	Location	Capacity (cfm)	OA Capacity (cfm)	Heat Recovery Wheel	Notes
ACF-1	Lab	Mechanical Penthouse	50,000	50,000	Y	-
ACF-2	Lab	Mechanical Penthouse	50,000	50,000	Y	-
ACF-3	Lab	Mechanical Penthouse	50,000	50,000	Y	-
ACF-4	Lab	Mechanical Penthouse	50,000	50,000	Y	-
ACF-5	Lab	Mechanical Penthouse	50,000	50,000	Y	-
ACF-6	Offices	Mechanical Penthouse	33,000	4,950	N	-
ACF-7	Offices	Mechanical Penthouse	33,000	4,950	N	-
ACF-8	Offices	Mechanical Penthouse	33,000	4,950	N	-
ACF-9	Animal Holding	Mechanical Penthouse	25,000	25,000	Y	-
ACF-10	Animal Holding	Mechanical Penthouse	25,000	25,000	Y	-
ACF-11	Quiet Labs	Mechanical Penthouse	13,000	13,000	Y	-
ACF-12	Clean Room	Mechanical Penthouse	51,000	51,000	Y	-
CRAC-1	LS/MS Server	Mechanical Room	14,600	-	N	40% Ethylene Glycol
ACU-1	MDF/IDF	Basement	1,250	-	N	Supplemental
ACU-2,3	LS DATA	Basement	3,750	-	N	Supplemental
ACU-4	TELECOM	First Floor	1,250	-	N	Supplemental
ACU-5	TELECOM	First Floor	1,250	-	N	Supplemental
ACU-8	TELECOM	Second Floor	1,250	-	N	Supplemental
ACU-9,10	IDF	Second Floor	3,750	-	N	Supplemental
ACU-11	LS DATE	Second Floor	1,250	-	N	Supplemental
ACU-12	TELECOM	Second Floor	1,250	-	N	Supplemental
ACU-13	TELECOM	Second Floor	1,250	-	N	Supplemental
ACU-14	IDF ROOM	Third Floor	1,250	-	N	Supplemental
ACU-15	TELECOM	Third Floor	1,250	-	N	Supplemental
ACU-16	ELEV MACHINE	Mechanical Penthouse	2,500	-	N	Supplemental
ACU-17	ELEV MACHINE	Mechanical Penthouse	2,500	-	N	Supplemental
ACU-18	BIOPHOTONICS	Second Floor	2,500	-	N	Supplemental
ACU-19	BOIPHOTONICS	Second Floor	2,500	-	N	Supplemental
ACU-20	BIOPHOTONICS	Second Floor	2,500	-	N	Supplemental

Table 18: Major Mechanical Equipment- Fan Coil Units

Designation	Service	Location	Air Quantity (cfm)	Total Cooling Capacity (MBH)	Heating Capacity (MBH)
FCUNQ012_1,2,3	Tunnel Corridor	Basement	600	12.9	21.8
FCUN160_1,2	Equipment Corridor	First Floor	600	12.9	-
FCUN270_1,2,3	Equipment Corridor	Second Floor	600	12.9	-
FCUN361_1,2	Equipment Corridor	Third Floor	600	12.9	-
FCUNP053	Electrical	Basement Mezzanine	1400	48.9	-

Table 19: Major Mechanical Equipment--Air to Air Heat Recovery Units

Designation	Service	Location	Air Quantity (cfm)	Wheel Size (in)	Motor rpm
HRW-1	ACF-1	Mechanical Penthouse	50,000	154 x 154	1800
HRW-2	ACF-2	Mechanical Penthouse	50,000	154 x 154	1800
HRW-3	ACF-3	Mechanical Penthouse	50,000	154 x 154	1800
HRW-4	ACF-4	Mechanical Penthouse	50,000	154 x 154	1800
HRW-5	ACF-5	Mechanical Penthouse	50,000	154 x 154	1800

Table 20: Major Mechanical Equipment-Plate and Frame Heat Exchangers

Designation	Service	Location	Type	Flow Rate (GPM)
HTX-1	Process Cooling Water	First Floor Mer.	Water to Water	897.7
HTX-2	Process Cooling Water	First Floor Mer.	Water to Water	897.7
HTX-3	Hot Water Heating	First Floor Mer.	Steam to Water	930
HTX-4	Hot Water Heating	First Floor Mer.	Steam to Water	930
HTX-5	Radiant Cooling Water Quiet Labs	Basement	Water to Water	75
HTX-6	Radiant Cooling Water Quiet Labs	Basement	Water to Water	75
HTX-7	Snow Melt System	First Floor Mer	Water to Water	25

Table 21: Major Mechanical Equipment-Clean Stem Generators

Designation	Service	Location	Clean Steam Capacity (lb/hr)	Steam Pressure (psig)
CSG-1	Laboratory	Penthouse	4,000	15
CSG-2	Laboratory	Penthouse	4,000	15
CSG-3	Laboratory	Penthouse	4,000	15

LOST USABLE SPACE

The mechanical system equipment and components encompass a large amount of the physical space within the building. Not only is floor area lost due to shaft rising through each floor and mechanical equipment rooms, but the building's floor to floor height needed to be increased in order to snugly fit all of the mechanical equipment underneath the structure and above the finished ceiling. A breakdown of the lost floor area and lost volume of the building is provided below.

Table 22: Lost Usable Area Breakdown

Floor	Lost Usable Area
Basement	9,050 SF
1st Floor	4,150 SF
2nd Floor	1,175 SF
3rd Floor	1,014 SF
4th Floor: Mechanical Penthouse	27,287 SF
Total Area Lost	42,676 SF

The overall building encompasses a total of 275,600 SF. Therefore, the area covered by mechanical systems for the building corresponds to 15.5% of the total usable area within the building.

The Millennium Science Complex has an average floor to floor height of 19 feet. An average of 9 feet is left for both structure and mechanical systems. An average estimate of 7 feet of plenum space can be used to calculate the volume of the MEP & Telecom distribution in the area not dedicated to the mechanical systems, 232,924 SF. The MEP & Telecom distribution system consumes 31% of the building's volume.

Table 23: Lost Usable Volume Breakdown

Average Building Floor to Floor Height	19 ft.
Average Mechanical Plenum Height	7 ft.
Building Area(without shaft and MEP space)	232,924 SF
Volume of Space from distribution systems	1,630,468 CF
Volume of Building	5,236,400 CF
Percentage of Building Volume dedicated to MEP & Telecom distribution	31%

FIRST COST BREAKDOWN

Cost information of the mechanical system was not available at the time of this report and thus not detailed at this time. The cost of the system and comparisons to alternatives will be investigated at a later time.

LEED NC v2.2: HVAC Focus

The Pennsylvania State University Millennium Science Complex has been designed to obtain LEED Gold Certification using the LEED NC v2.2 rating system. The Millennium Science Complex plans to receive points for obtaining credits in the following LEED NC v2.2 sub categories.

Table 24: LEED Credit Breakdown

Category	Possible Points
Sustainable Sites	11/14
Water Efficiency	3/5
Energy & Atmosphere	5/17
Materials & Resources	5/13
Indoor Environmental Quality	12/15
Innovation % Design Process	5/5
TOTAL	**41/69**

Specifically, the mechanical system accounts for 19 of the 40

WATER EFFICENCY: 3 of 5 Credits

WE CREDIT 1.1: WATER EFFICIENT LANDSCAPING, 50% REDUCTION, 1 POINT
WE CREDIT 1.2: WATER EFFICIENT LANDSCAPING, NO POTABLE USE OR NO IRRIGATION, 1 POINT
The climate of University Park, PA will provide the required rainfall for the vegetation of the site. Plants were chosen that are native to the region and will not require additional irrigation. The project earns both of these credits.

WE CREDIT 3.1: WATER USE REDUCTION, 20%, 1 POINT
The building contains highly efficient water closets, lavatory faucets, showers, kitchen sinks and waterless urinals that result in at least a 20% reduction in the building's water use.

ENERGY & ATMOSPHERE: 5 (6) of 17 Credits

EA PREREQUISITE 1: FUNDAMENTAL BUILDING SYSTEMS COMMISSIONING
The project will follow the commissioning standards outlined in the credit.
EA PREREQUISITE 2: MINIMUM ENERGY PERFORMANCE
The building and systems comply with the prescriptive and mandatory elements of ASHRAE Standard 90.1-2004
EA PREREQUISITE 3: FUNDAMENTAL REFRIGERANT MANAGEMENT
CFC-based refrigerants have not been specified for use in any of the HVAC equipment within the building.

EA CREDIT 1: OPTIMIZE ENERGY PERFORMANCE, 2 POINTS

A whole building energy simulation was completed using ASHRAE Standard 90.1-2004, Appendix G. The building design energy cost savings percentage is at least 14%. Two points are awarded for this level of energy optimization.

EA CREDIT 3: ENHANCED COMMISSIONING, 1 POINT

The design specifications call for the building to follow the necessary steps to qualify for this credit.

EA CREDIT 4: ENHANCED REFRIGERANT MANAGEMENT, 1 POINT

No Halon or HCFC based refrigerants were used in HVAC equipment.

EA CREDIT 5: MEASUREMENT AND VERIFICATION (UNDEDCIDED, 1 POINT)

The project may or may not achieve this credit. To achieve EA Credit 5, the Millennium Science Complex would have to instill a plan to continually monitor the energy consumption of the building to ensure the building continually performs efficiently

EA CREDIT 6: GREEN POWER, 1 POINT

Penn State committed to purchasing an annual supply of 83,600 megawatts of renewable energy in 2006 for the next 5 years. This is equivalent to 20% of what the university's annual supply. This energy is split between nationally based Low Impact Hydropower Institute's hydropower (39%), biomass (20%), wind energy (20%), and Pennsylvania based wind energy (21%).

INDOOR ENVIRONMENTAL QUALITY: 12 of 15 Credits

EQ PREREQUISITE 1: MINIMUM IAQ PERFORMANCE

EQ PREREQUISITE 2: ENVIRONMENTAL TOBACCO SMOKE CONTROL

Both prerequisites are required to be met.

EQ CREDIT 1: OUTDOOR AIR DELIVERY MONITORING, 1 POINT

CO_2 monitoring devices are located within air handling units and densely occupied conference rooms

EQ CREDIT 3.1: CONSTRUCTION IAQ MANAGEMENT PLAN, DURING OCCUPANCY, 1 POINT

EQ CREDIT 3.2: CONSTRUCTION IAQ MANAGEMENT PLAN, BEFORE OCCUPANCY, 1 POINT

During the construction of the building, an IAQ plan was laid out and followed. Before the building is occupied the systems will be ran to purge the spaces of any remaining construction related contaminants.

EQ CREDIT 4.1: LOW EMITTING MATERIALS, ADHESIVES & SEALANTS, 1 POINT

EQ CREDIT 4.2: LOW EMITTING MATERIALS, PAINTS & COATING, 1 POINT

EQ CREDIT 4.3: LOW EMITTING MATERIALS, CARPET SYSTEMS, 1 POINT

EQ CREDIT 4.4: LOW EMITTING MATERIALS, COMPOSITE WOOD & AGRIFIBER, 1 POINT

All material s that apply to the above credits meet tolerances for VOC content limits and other prescriptive requirements.

EQ CREDIT 5: INDOOR CHEMICAL & POLLUTANT SOURCE CONTROL, 1 POINT

Building entrances contain grilles that serve to collect dirt from occupants as they enter the building. Also, since the laboratory rooms have the likelihood of producing chemicals harmful to indoor air quality, each room is tied into an exhaust system that purges exhaust straight out of the building.

EQ CREDIT 6.1: CONTROLLABILITY OF SYSTEMS: LIGHTING, 1 POINT

Lighting controls are provided for at least 90% of the individual spaces in the building as well as controls for all multi-person spaces.

EQ CREDIT 7.2: THERMAL COMFORT, VERIFICATION, 1 POINT

The credit requires a survey of the new building's occupants thermal satisfaction from 6 to 18 months after occupancy to ensure that no more than 20% of occupants are thermally uncomfortable and remediation if 20% of occupants are dissatisfied.

EQ CREDIT 8.1: DAYLIGHT & VIEWS, DAYLIGHT 75% OF SPACES, 1 POINT

EQ CREDIT 8.2: DAYLIGHT & VIEWS, DAYLIGHT 90% OF SPACES, 1 POINT

The building is required to use natural daylight to produce the required illumination levels with 90% of the regularly occupied spaces. The use of natural daylight connects the occupant with the outdoors and has been linked with improvements in mood and productivity.

OVERALL EVALUATION

The mechanical systems in the Millennium Science Complex provide an intricate and reliable design to accommodate the diverse laboratories and general spaces for the Material and Life Sciences. Through the programs' pursuit to achieve LEED Gold Certification, numerous technologies and equipment were utilized to reduce the energy usage. Although the building's operating history does not exist currently, reasonable assumptions were made to estimate the energy performance of the building.

Enthalpy heat recovery wheels and runaround reheat coils that service the laboratories and animal control facilities have proven to be successful in other designs and offset the additional energy use associated with a 100% outdoor air system. Connecting into the campus steam and chilled water lines reduces the amount of space that would need to be devoted to large mechanical equipment such as chillers and boilers. VAV systems are proven to reduce energy usage and have been widely used throughout the building industry.

The Millennium Science Complex has been designed to a high standard in all aspects. It is likely that Penn State investigated many viable systems and selected the approach that best fit the university's current and future plans and overall growing emphasis on sustainable and responsible building. Future reports will investigate opportunities for improvement in energy usage and synergy with other design disciplines within the collaborative environment of the Integrated Project Delivery/ Building Information Modeling thesis teams.

INTEGRATED PROJECT DELIVERY/BUILDING INFORMATION MODELING

COORDINATION MODELING

All disciplines have received a set of basic BIM models from the design team, developed in Autodesk Revit 2011 platforms. While these are a useful start to coordinating design information between disciplines, they are not a complete set of construction documents. The mechanical model contains only the main risers and runs, not including the smaller branch ducting. It also does not include any of the dense gas pipework that are meant to supply the laboratory sectors. While these major items are missing, it may be due to a small cost-benefit relationship of this additional modeling. With such a large above ceiling plenum, it may not have been cost effective to model these extra details for the benefits of coordination.

In the picture below, it is easy to see the complexity of the building systems in the Millennium Science Complex. The tolerances and clearances between electrical (gray conduit), mechanical (blue ductwork), structural (red members), and architectural systems are very tight. Through accurate modeling, our research team hopes to better coordinate areas of congestion. The most congested areas within the third floor will be surrounding the four mechanical shafts. By coordinating these areas, coordination modeling will be able to produce the most significant benefits.

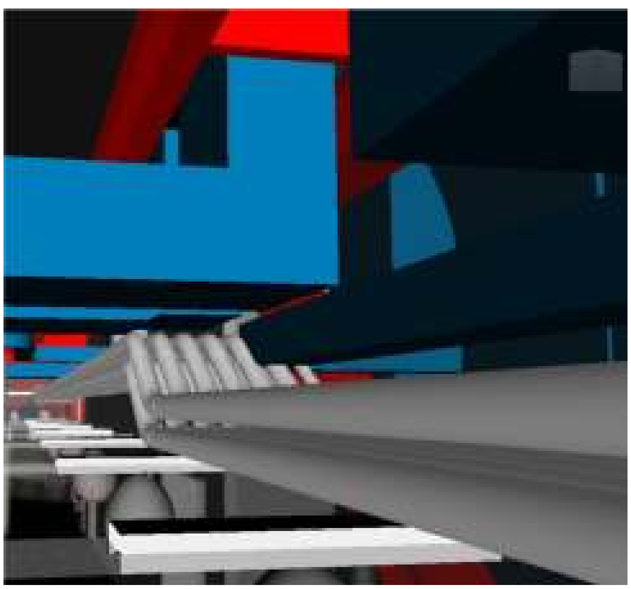


Figure 12: Screenshot from the Coordination Model of All Disciplines

EXISTING CLASH DETECTION

All discipline models have been brought together in Autodesk Navisworks Manage 2011 for a collision coordination model. While there are a few instances of interdisciplinary collisions, as seen below, the models in general have been coordinated very well. They do not, however, accurately represent the actual ceiling conditions, as many things are not modeled. Mechanically, there is very little branch ductwork and no diffusers modeled. Electrically there is no branch conduit modeled. While in most cases these aspects might not cause serious collision issues, there is potential for them to cause problems in the congested areas highlighted in the preceding sections. It may be worthwhile to model in greater detail these other components to fully realize the congested conditions that will be found in the field.

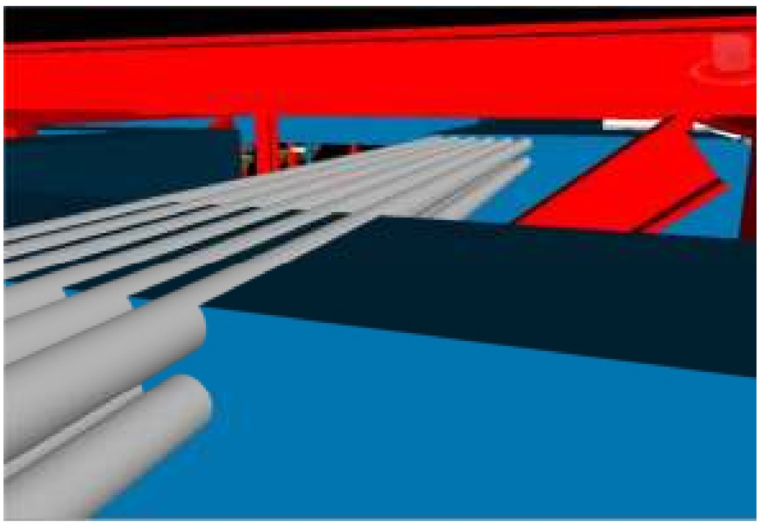


Figure 13: Example of Existing Mechanical Ductwork and Electrical Conduit Collision

ENERGY MODELING

In order to achieve the goals of useful integration and energy modeling, there was a great effort to share project design information through our models. Revit models were created with spaces that had crucial information fields for energy analysis. With the input of our mechanical and electrical engineers' design standards, the model successfully exported embedded building information.

When opened for analysis in a separate program (Trane TRACE), the model retained such important information as room names, floor areas, occupancy, lighting power densities, and equipment load densities. This information would be the basis of our load calculations, energy analysis, and system analysis.

The model was unable however to transfer accurate information about the roof areas and exterior walls, which were later manually updated. These errors stem from the creation methodology and complexity of the architecture model, and would require a significant time investment to ensure their correctness.

The workflow for this space information process would begin with a model of the architecture, most likely completed by the architect. When rooms are developed, the architect could create corresponding spaces. These spaces could then be embedded with information by any party, i.e. occupancy densities from the lab planner, lighting power densities by the electrical engineer. Once building information has been modeled, it could then be exported by the architect for the mechanical engineer to run further analysis. The mechanical engineer must still check to ensure the quality and accuracy of the export, but this model now contains crucial information that previously would have been held by multiple parties in multiple locations. With space information modeling, the model becomes a better tool for sharing project design information.

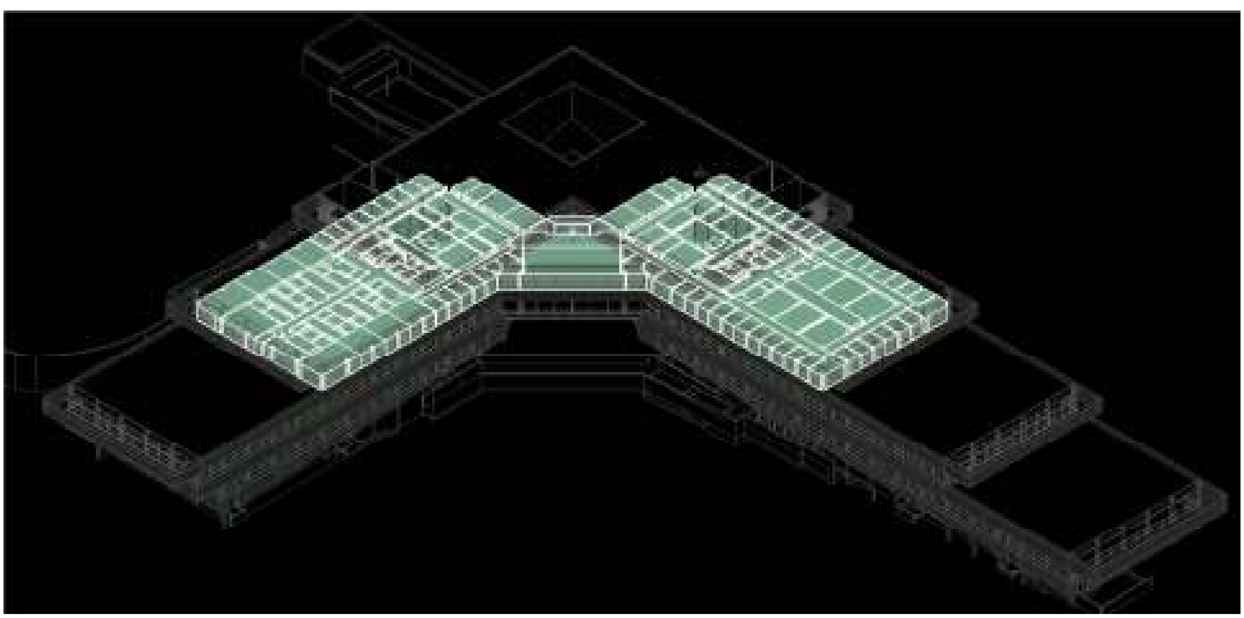


Figure 14: Exported Spaces from Revit Model with Information Embedded

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APPENDIX B: LEED Credit Summary

LEED for New Construction v 2.2
Registered Project Checklist

Project Name: PSU- Millennium Science Complex

Project Address: University Park, PA

Yes	?	No		
41	6	22	Project Totals (Pre-Certification Estimates)	69 Points
	GOLD		**Certified**: 26-32 points **Silver**: 33-38 points **Gold**: 39-51 points **Platinum**: 52-69 points	

Yes	?	No			
11	0	3	Sustainable Sites		14 Points
Yes			Prereq 1	**Construction Activity Pollution Prevention**	Required
1	0	0	Credit 1	**Site Selection**	1
1	0	0	Credit 2	**Development Density & Community Connectivity**	1
0	0	1	Credit 3	**Brownfield Redevelopment**	1
1	0	0	Credit 4.1	**Alternative Transportation**, Public Transportation	1
1	0	0	Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
0	0	1	Credit 4.3	**Alternative Transportation**, Low-Emitting & Fuel Efficient Vehicles	1
1	0	0	Credit 4.4	**Alternative Transportation**, Parking Capacity	1
1	0	0	Credit 5.1	**Site Development**, Protect or Restore Habitat	1
1	0	0	Credit 5.2	**Site Development**, Maximize Open Space	1
1	0	0	Credit 6.1	**Stormwater Design**, Quantity Control	1
1	0	0	Credit 6.2	**Stormwater Design**, Quality Control	1
1	0	0	Credit 7.1	**Heat Island Effect**, Non-Roof	1
1	0	0	Credit 7.2	**Heat Island Effect**, Roof	1
0	0	1	Credit 8	**Light Pollution Reduction**	1

Yes	?	No			
3	1	1	Water Efficiency		5 Points
1	0	0	Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
1	0	0	Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
0	0	1	Credit 2	**Innovative Wastewater Technologies**	1
0	0	0	Credit 3.1	**Water Use Reduction**, 20% Reduction	1
1	1	0	Credit 3.2	**Water Use Reduction**, 30% Reduction	1

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Yes	?	No				
5	3	9	**Energy & Atmosphere**			17 Points
Yes			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**		Required
Yes			Prereq 1	**Minimum Energy Performance**		Required
Yes			Prereq 1	**Fundamental Refrigerant Management**		Required
*Note for EAc1: All LEED for New Construction projects registered after June 26, 2007 are required to achieve at least two (2) points.						
2	2	6	Credit 1	**Optimize Energy Performance**		1 to 10
				Credit 1.1	10.5% New Buildings / 3.5% Existing Building Renovations	1
			-->	Credit 1.2	14% New Buildings / 7% Existing Building Renovations	2
				Credit 1.3	17.5% New Buildings / 10.5% Existing Building Renovations	3
				Credit 1.4	21% New Buildings / 14% Existing Building Renovations	4
				Credit 1.5	24.5% New Buildings / 17.5% Existing Building Renovations	5
				Credit 1.6	28% New Buildings / 21% Existing Building Renovations	6
				Credit 1.7	31.5% New Buildings / 24.5% Existing Building Renovations	7
				Credit 1.8	35% New Buildings / 28% Existing Building Renovations	8
				Credit 1.9	38.5% New Buildings / 31.5% Existing Building Renovations	9
				Credit 1.10	42% New Buildings / 35% Existing Building Renovations	10
0	0	3	Credit 2	**On-Site Renewable Energy**		1 to 3
				Credit 2.1	2.5% Renewable Energy	1
				Credit 2.2	7.5% Renewable Energy	2
				Credit 2.3	12.5% Renewable Energy	3
1	0	0	Credit 3	**Enhanced Commissioning**		1
1	0	0	Credit 4	**Enhanced Refrigerant Management**		1
0	1	0	Credit 5	**Measurement & Verification**		1
1	0	0	Credit 6	**Green Power**		1

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Yes	?	No			
5	2	6	**Materials & Resources**		**13 Points**
Yes			Prereq 1	**Storage & Collection of Recyclables**	Required
0	0	1	Credit 1.1	**Building Reuse,** Maintain 75% of Existing Walls, Floors & Roof	1
0	0	1	Credit 1.2	**Building Reuse,** Maintain 95% of Existing Walls, Floors & Roof	1
0	0	1	Credit 1.3	**Building Reuse,** Maintain 50% of Interior Non-Structural Elements	1
1	0	0	Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
1	0	0	Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
0	0	1	Credit 3.1	**Materials Reuse,** 5%	1
0	0	1	Credit 3.2	**Materials Reuse,** 10%	1
1	0	0	Credit 4.1	**Recycled Content,** 10% (post-consumer + 1/2 pre-consumer)	1
0	1	0	Credit 4.2	**Recycled Content,** 20% (post-consumer + 1/2 pre-consumer)	1
1	0	0	Credit 5.1	**Regional Materials,** 10% Extracted, Processed & Manufactured	1
0	1	0	Credit 5.2	**Regional Materials,** 20% Extracted, Processed & Manufactured	1
0	0	1	Credit 6	**Rapidly Renewable Materials**	1
1	0	0	Credit 7	**Certified Wood**	1

Yes	?	No			
12	0	3	**Indoor Environmental Quality**		**15 Points**
Yes			Prereq 1	**Minimum IAQ Performance**	Required
Yes			Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	Required
1	0	0	Credit 1	**Outdoor Air Delivery Monitoring**	1
0	0	1	Credit 2	**Increased Ventilation**	1
1	0	0	Credit 3.1	**Construction IAQ Management Plan,** During Construction	1
1	0	0	Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
1	0	0	Credit 4.1	**Low-Emitting Materials,** Adhesives & Sealants	1
1	0	0	Credit 4.2	**Low-Emitting Materials,** Paints & Coatings	1
1	0	0	Credit 4.3	**Low-Emitting Materials,** Carpet Systems	1
1	0	0	Credit 4.4	**Low-Emitting Materials,** Composite Wood & Agrifiber Products	1
1	0	0	Credit 5	**Indoor Chemical & Pollutant Source Control**	1
1	0	0	Credit 6.1	**Controllability of Systems,** Lighting	1
0	0	1	Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
0	0	1	Credit 7.1	**Thermal Comfort,** Design	1
1	0	0	Credit 7.2	**Thermal Comfort,** Verification	1
1	0	0	Credit 8.1	**Daylight & Views,** Daylight 75% of Spaces	1
1	0	0	Credit 8.2	**Daylight & Views,** Views for 90% of Spaces	1

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Yes	?	No			
5	0	0	**Innovation & Design Process**		5 Points
1	0	0	Credit 1.1	**Innovation in Design:** Provide Specific Title	1
1	0	0	Credit 1.2	**Innovation in Design:** Provide Specific Title	1
1	0	0	Credit 1.3	**Innovation in Design:** Provide Specific Title	1
1	0	0	Credit 1.4	**Innovation in Design:** Provide Specific Title	1
1	0	0	Credit 2	**LEED® Accredited Professional**	1

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APPENDIX C: ASHRAE CLIMATIC DESIGN INFORMATION

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ALTOONA BLAIR CO ARPT, PA, USA

WMO#: **725126**

Lat **40.30N** Long **78.32W** Elev **1470** StdP **13.93** Time Zone **-5.00 (NAE)** Period **82-06** WBAN **14736**

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
1	4.7	9.6	-6.4	4.1	7.5	-1.7	5.3	11.9	27.5	29.4	24.9	27.1	8.9	260

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	19.3	88.5	72.0	85.7	70.7	83.0	69.6	74.7	83.9	73.2	82.0	71.6	79.8	8.0	280

Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours 8 to 4 & 55/69
0.4%			1%			2%			0.4%		1%		2%		
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	
72.0	125.0	79.6	70.3	118.0	77.7	69.1	112.9	76.2	39.1	83.9	37.6	82.0	36.3	79.9	731

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%	WB	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
21.9	18.8	17.2	82.4	-2.6	92.5	8.1	3.5	-8.4	95.0	-13.2	97.1	-17.7	99.1	-23.6	101.6

Monthly Climatic Design Conditions

			Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours	Tavg		50.4	27.9	30.6	38.1	49.5	58.8	67.5	71.7	70.0	62.6	52.2	42.6	31.9
	Sd			11.40	9.59	10.63	9.41	8.00	6.47	5.14	5.51	7.30	8.33	9.28	10.28
	HDD50		2679	690	546	398	121	15	0	0	0	4	76	259	570
	HDD65		5959	1150	964	837	472	226	50	7	19	130	404	673	1027
	CDD50		2810	4	2	28	105	287	526	672	619	381	143	36	7
	CDD65		617	0	0	2	6	33	126	214	173	56	7	0	0
	CDH74		4099	0	0	16	76	336	1003	1711	1299	417	40	1	0
	CDH80		1333	0	0	2	10	67	260	524	375	94	1	0	0
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4%	DB		61.1	61.4	75.6	81.4	85.5	89.8	92.3	91.5	87.4	78.5	70.7	64.4
		MCWB		55.9	50.0	59.6	63.6	68.3	72.5	73.0	73.5	69.5	64.5	58.6	56.9
	2%	DB		55.1	53.8	67.5	75.5	81.6	86.0	88.8	87.5	82.4	74.2	65.0	57.8
		MCWB		49.5	45.7	54.8	59.4	65.7	70.6	72.8	71.6	67.8	62.6	55.3	52.0
	5%	DB		48.4	48.6	60.8	70.2	78.0	83.1	85.7	84.0	78.9	70.2	61.1	51.7
		MCWB		43.2	41.9	51.2	57.2	64.0	69.5	71.5	70.4	66.3	60.5	54.1	46.1
	10%	DB		42.5	44.4	54.4	65.1	73.3	80.2	82.4	81.2	75.2	66.2	57.0	45.7
		MCWB		37.8	39.3	46.6	54.0	61.5	68.0	70.4	69.2	65.5	58.5	51.2	40.8
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4%	WB		57.3	52.5	61.6	65.7	71.4	76.1	77.4	76.2	73.2	68.2	61.4	58.5
		MCDB		60.2	58.5	72.5	75.9	81.9	84.2	87.2	85.9	81.4	75.3	66.5	64.2
	2%	WB		51.0	46.8	56.5	62.0	68.5	73.4	74.9	74.1	70.7	65.2	58.4	53.5
		MCDB		54.4	52.2	64.8	71.7	77.8	81.7	84.4	83.5	78.0	70.2	63.1	57.6
	5%	WB		43.5	43.1	51.6	59.1	66.1	71.4	73.3	72.5	68.9	62.4	55.4	46.9
		MCDB		47.4	47.8	59.5	68.0	74.7	79.6	82.3	81.0	76.2	68.2	59.3	50.5
	10%	WB		38.0	39.5	47.1	55.9	63.6	69.8	71.8	70.9	67.2	59.5	51.7	41.6
		MCDB		42.3	43.8	53.9	64.0	71.2	77.6	80.0	78.4	72.8	65.4	56.6	45.8
Mean Daily Temperature Range		MDBR		12.9	14.5	16.7	19.5	19.6	19.2	19.3	19.6	19.3	18.3	14.9	13.0
	5% DB	MCDBR		18.8	21.3	25.0	26.0	25.5	22.6	22.8	23.3	24.0	23.7	20.6	19.3
		MCWBR		15.1	15.8	15.9	15.0	12.7	10.9	10.1	10.7	12.0	13.7	14.4	15.1
	5% WB	MCDBR		17.2	18.8	22.5	22.9	21.6	19.6	19.0	19.8	18.1	19.6	17.6	17.9
		MCWBR		14.9	14.9	15.8	14.9	12.3	10.7	9.6	10.3	10.6	12.8	14.8	15.6
Clear Sky Solar Irradiance	taub			0.301	0.324	0.361	0.361	0.415	0.473	0.482	0.486	0.392	0.349	0.318	0.300
	taud			2.397	2.247	2.155	2.248	2.069	1.910	1.913	1.879	2.215	2.330	2.438	2.472
	Ebn,noon			274	281	281	289	274	258	254	248	268	269	265	265
	Edh,noon			29	37	44	43	52	61	60	60	41	34	28	26

CDD*n*	Cooling degree-days base n°F, °F-day	Lat	Latitude, °	Period	Years used to calculate the design conditions
CDH*n*	Cooling degree-hours base n°F, °F-hour	Long	Longitude, °	Sd	Standard deviation of daily average temperature, °F
DB	Dry bulb temperature, °F	MCDB	Mean coincident dry bulb temperature, °F	StdP	Standard pressure at station elevation, psi
DP	Dew point temperature, °F	MCDBR	Mean coincident dry bulb temp. range, °F	taub	Clear sky optical depth for beam irradiance
Ebn,noon	} Clear sky beam normal and diffuse hori-	MCDP	Mean coincident dew point temperature, °F	taud	Clear sky optical depth for diffuse irradiance
Edh,noon	} zontal irradiances at solar noon, Btu/h/ft2	MCWB	Mean coincident wet bulb temperature, °F	Tavg	Average temperature, °F
Elev	Elevation, ft	MCWBR	Mean coincident wet bulb temp. range, °F	Time Zone	Hours ahead or behind UTC, and time zone code
Enth	Enthalpy, Btu/lb	MCWS	Mean coincident wind speed, mph	WB	Wet bulb temperature, °F
HDD*n*	Heating degree-days base n°F, °F-day	MDBR	Mean dry bulb temp. range, °F	WBAN	Weather Bureau Army Navy number
Hours 8/4 & 55/69	Number of hours between 8 a.m. and 4 p.m with DB between 55 and 69 °F	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East	WMO#	World Meteorological Organization number
HR	Humidity ratio, grains of moisture per lb of dry air			WS	Wind speed, mph

WORKS CITED

1. ANSI/ASHRAE. (2004). *ASHRAE Standard 62.1.* Atlanta: ASHRAE.
2. ANSI/ASHRAE/IESNA. (2004). *ASHRAE Standard 90.1.* Atlanta: ASHRAE.
3. ASHRAE. (2009). *ASHRAE Handbook of Fundamentals.* Atlanta: ASHRAE.
4. National Research Council. (1996). *Guide for the Care and Use of Laboratory Animals.* National Academy Press. *Table 2.4: Recommended Dry-Bulb Temperatures for Common Laboratory Animals*
5. Energy Information Administration. (2008). *Energy Consumption by Sector.* Washington DC: Department of Energy.
6. Torcellini, M. D. (2007). *Source Energy and Emission Factors for Energy Use in Buildings.* Golden: National Renewable Energy Laboratory.
7. USGBC LEED NC v2.2
8. Office of Physical Plant. (2009). *Utility Fact Sheet University Park Campus.* University Park, PA: OPP.
9. Office of Physical Plant. (2010). *Division 23: Heating Ventilating, and Air-Conditioning (HVAC).* University Park, PA: OPP.