Tech Report Two

Building and Plant Energy Analysis

Biobehavioral Health Building

The Pennsylvania State University | Biobehavioral Health Building | University Park, PA | Mechanical | Ling | Jake Copley

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Executive Summary

The purpose of tech report two is to conduct a load and energy analysis of the Biobehavioral Health Building (BBH) and determine its heating and cooling loads, annual operating costs and cost per square foot. DesignBuilder v1.4.0.056 with EnergyPlus v2.1.0 was used for the load analysis and energy consumption of BBH.

After a simulation was completed the modeled heating and cooling loads were compared with the minimum loads specified in the construction documents. The annual operating costs and costs per square foot for BBH were also compared with values determined by the mechanical engineer's energy model results.

A 3-D model was created using DesignBuilder and simulations were run within DesignBuilding using EnergyPlus simulation software. The results from DesignBuilder were also compared to the results of the mechanical engineers energy model who used Carrier HAP v4.4. It was determined that BBH consumes about 56 kBTU/SF-year. BBH is calculated to cost $1.28/SF-year or $119,265 per year.

Building Overview

The Biobehavioral Health Building (BBH) is a 93,500 square foot new construction building located at The Pennsylvania State University Main Campus, in University Park, PA and a overall project cost of $48.1 million. There are four floors above ground, one below and a mechanical penthouse. The site was originally home to a parking lot and an existing 12,000 square foot Henderson Bridge Building, which was building in 1958. The new Biobehavioral Health Building is located south of the Henderson North Building between the Old Main lawn and the HUB lawn (Figure 1). It's expected completion date is November of 2012.

Figure 1: *Arial view from Bing.com showing location.*

Occupant

Biobehavioral Health, from the College of Health and Human Development, will occupy the majority of the first floor and the entire second floor. On the third floor is space allocated for The Prevention Research Center. The Center for Aging and the Center for Human Development and Family Research in Diverse Contexts share the fourth floor. Each floor consists of a mix of offices, projects and research spaces. The ground floor contains a 200 seat lecture hall and the first floor has two 35 seat general purpose classrooms.

Primary Project Team

Owner	The Pennsylvania State University	www.opp.psu.edu
Architect	Bohlin Cywinski Jackson	www.bcj.com
CM	Massaro CM Services	www.massarocorporation.com
MEP/Fire Protection	Bruce E. Brooks Associates	www.brucebrooks.com
Structural Engineer	Robert Silman Associates	www.rsapc.com
Civil Engineer	Gannett Fleming, Inc.	www.gannettfleming.com
Landscape Architect	Michael Vergason	www.vergason.net
Geotech Consultant	CMT Laboratories, Inc.	www.cmtlaboratories.com
GC	L.S. Fiore	www.lsfiore.com

Architecture

Due to the historic nature of Henderson North, built in 1933, the BBH was designed to be aesthetically complimentary to Henderson North. The differences between the two buildings are responses to the growth of sustainable design and the need for student activities. The building is served with main double loaded corridors down the middle of the building connecting the three main entrances on the east and west sides of the building. General purpose classrooms are located on the ground and first floor for ease of access for students. Offices, project and research spaces are located on the upper floors.

Figure 2: *West entrance off Old Main lawn.*

Figure 3: *Entrance off the HUB lawn.*

Figure 4: *Southeast entrance.*

Limestone and brick clad the building paying their respects to Henderson North. The limestone veneer wraps into the main entry ways on both the east and west entrances. All three entrances are located on heavy cross campus traffic areas. The West entrance is off the Old Main lawn (Figure 2). Another entrance is located on the HUB lawn (Figure 3) on the Northeast corner of the building along with the third entrance on the Southeast corner (Figure 4). Salvaged Elm wood from the Penn State Campus can be seen as accent pieces, benches and cabinetry throughout the building.

BBH has two main sustainable features. The first is a green roof that covers approximately fifty percent of the roof area. Second, complimenting the green roof is a cistern that collects rainwater runoff to be used for landscape maintenance. The use of a cistern is one of the first buildings to use the concept to reduce storm runoff into the storm system reducing the stress on the system during a heavy rain storm. BBH is located in the University Planned District (UPD). Per Pennsylvania State University standards, Penn State requires all future buildings on the Penn State Campuses must be LEED Certified. To help improve energy efficiency, BBH has been design to be in conformance with the International Energy Conservation Code.

The facade is very similar to Henderson North with limestone veneer up to the second floor followed by brick on the remaining floors. There are also limestone accent pieces around the building again in similar fashion to Henderson North. On the northeast and southeast corners of the building there are glass curtain walls surrounding the main stairwell and entrances.

Mechanical System Summary

The mechanical system of the Biobehavioral Health Building is composed of six variable air volume air handling units with economizers. The air handlers are divided by zone, AHU-1 and 5 service the core of the building, AHU-2 serves the classrooms, AHU-3 and 4 serve the south and north offices respectively and finally AHU-6 serves the conference rooms. BBH also uses perimeter radiant heat.

BBH is fed off the campus steam and chilled water loops which provide all heating and cooling needs along with domestic hot water requirements. Steam from the campus loop is fed through a plate heat exchanger which transfers heat to the building hot water loops.

System Design Load Estimation

Load Assumptions

An energy load analysis was performed to determine heating and cooling loads along with annual operating costs and a cost per square foot basis. The information below are the data used to compute the estimated heating and cooling loads.

Walls

The U-values shown in Table 2.1 were calculated from walls sections found in the construction documents. There are several wall types used throughout the building but only a few were used as typical conditions

Table 2.1: Wall U-values		
Construction	**U-value (BTU/h SF F)**	**Source**
External Walls	0.082	CD's
Floors	0.578	CD's
Green Roof	0.044	CD's
Pitched Roof	0.066	CD's
Window	0.423	Assumption

Occupancy and Ventilation

Occupied outdoor airflow (OA) rates from the air handling unit schedules were used and average over the total occupied space in the building. This average occupied OA rate was determined to be 0.147CFM/SF. The building was assumed to follow an occupancy activity level of a typical office building. Occupancy schedules are used for HVAC controlled (Table2.3). The occupant density (people/SF) was determined to be about 1 person/100 SF, this was determined using the estimated occupancy from design documents.

Infiltration

The infiltration rate was assumed to be 0.5 air changes per hour. No infiltration was given in the construction documents so an assumption was made to account for infiltration effects.

Lighting and Equipment Loads

Table 2.2 below contains estimated lighting and equipment loads that can be found throughout the building.

Table 2.2: Lighting and Equipment Loads		
Space/Equipment	**Load**	**Source**
DHW Consumption (gal/SF/day)	0.008099	Assumption
Computer Gain (W/SF)	0.2	Assumption
Office Equipment Gain (W/SF)	2	Assumption
Heavy Mechanical (W/SF)	10	Assumption
Heavy Electrical (W/SF)	5	Assumption
Light Electrical (W/SF)	2	Assumption
Server Room (W/SF)	10	Assumption
Lighting Density (W/SF)	1	Assumption

Weather Data

TMY2 weather data from the city of Pittsburg, PA was used in the load and energy simulation. Pittsburg, PA weather data was chosen to model a State College, PA site because both cities have similar insolation exposure levels.

Schedules

BBH is primarily an office building but also supports three general purpose classroom spaces. Office, labs and support areas are assigned to run on identical schedules. General purpose classroom spaces have a slightly modified scheduled. All schedule values were obtained from the Owner Project Requirements. The schedule used in this analysis can be seen below in Table 2.3.

Table 2.3: BBH Occupancy Schedules			
Space	**Monday-Friday**	**Weekends**	**Holiday**
Classrooms	7am to 11pm	Unoccupied with Override	Heating Setback: 50F Cooling Setback: 85F
Office, Labs, Support Spaces	7am to 8pm		

PSU has holiday setback temperatures for heating and cooling of 50F and 85 F respectively. Setback temperatures are used during the periods of Christmas through New Years, Memorial Day, July 4th, Labor Day and Thanksgiving Day.

Results

As shown in Table 2.4 below, the modeled cooling load is about 20% less than the designed cooling load. This resulted in 503 SF/ton (modeled load) compared to 438 SF/ton (designed load). Conversely, the modeled heating load is about 75% 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.

Table 2.4: Modeled vs. Designed Heating and Cooling Loads		
System	**Load**	**SF Per Basis**
Cooling Modeled (Tons)	155	503 SF/ton
Cooling Designed (Tons)	178	438 SF/ton
Heating Modeled (kBTU/hr)	3073	25 SF/kBTU
Heating Designed (kBTU/hr)	1758	44 SF/kBTU
Modeled SA CFM	65907	0.845 CFM/SF
Design SA CFM	69900	0.896 CFM/SF

Energy Consumption and Operating Costs

Assumptions

BBH receives all its energy through campus distribution loops, from various central plant/distribution sites. Table 2.5 shows the campus rates used for estimated annual operating costs.

Table 2.5: Energy Rates	
Fuel	**Campus Rates**
Electricity ($/kWh)	0.09387
Chilled Water ($/ton-hour)	0.22
Steam ($/1000lb)	24.59

Results

Table 2.6 below shows the distribution of energy use by the various building systems. Figure 5 below shows a breakdown of the percentage of energy use by each system in the building, this can be used to help determine where future energy savings could occur. As shown in Table 2.6 and Figure 2.5 the heating load dominates all other loads by using 53% of the buildings total energy demand. The building system with the next largest load is the plug load at 20% of the total building demand.

Table 2.6: Annual Building Loads						
Source	**kBTU**	**kWh**	**Ton-hour**	**Lbs Steam (x1000)**	**Utility Rate**	**Cost ($/Year)**
Heating	2,364,136	692,889	-	1,980	24.59	$48,689
Cooling	680,158	199,343	56,680	-	0.22	$12,470
DHW	173,522	50,856	-	145	24.59	$3,574
Plug Load	914,994	268,169	-	-	0.09387	$25,173

Table 2.6: Annual Building Loads						
Source	kBTU	kWh	Ton-hour	Lbs Steam (x1000)	Utility Rate	Cost ($/Year)
Lighting	770,221	225,739	-	-	0.09387	$21,190
System Fans	75,824	22,223	-	-	0.09387	$2,086
System Pumps	221,155	64,817	-	-	0.09387	$6,084
Total	5,200,010	1,524,036	433,334	4,355	-	$119,265

With a total building area of 93,500 SF, BBH consumes about 56kBTU/SF or 16 kWh/SF-year and costs about $1.28/SF-year.

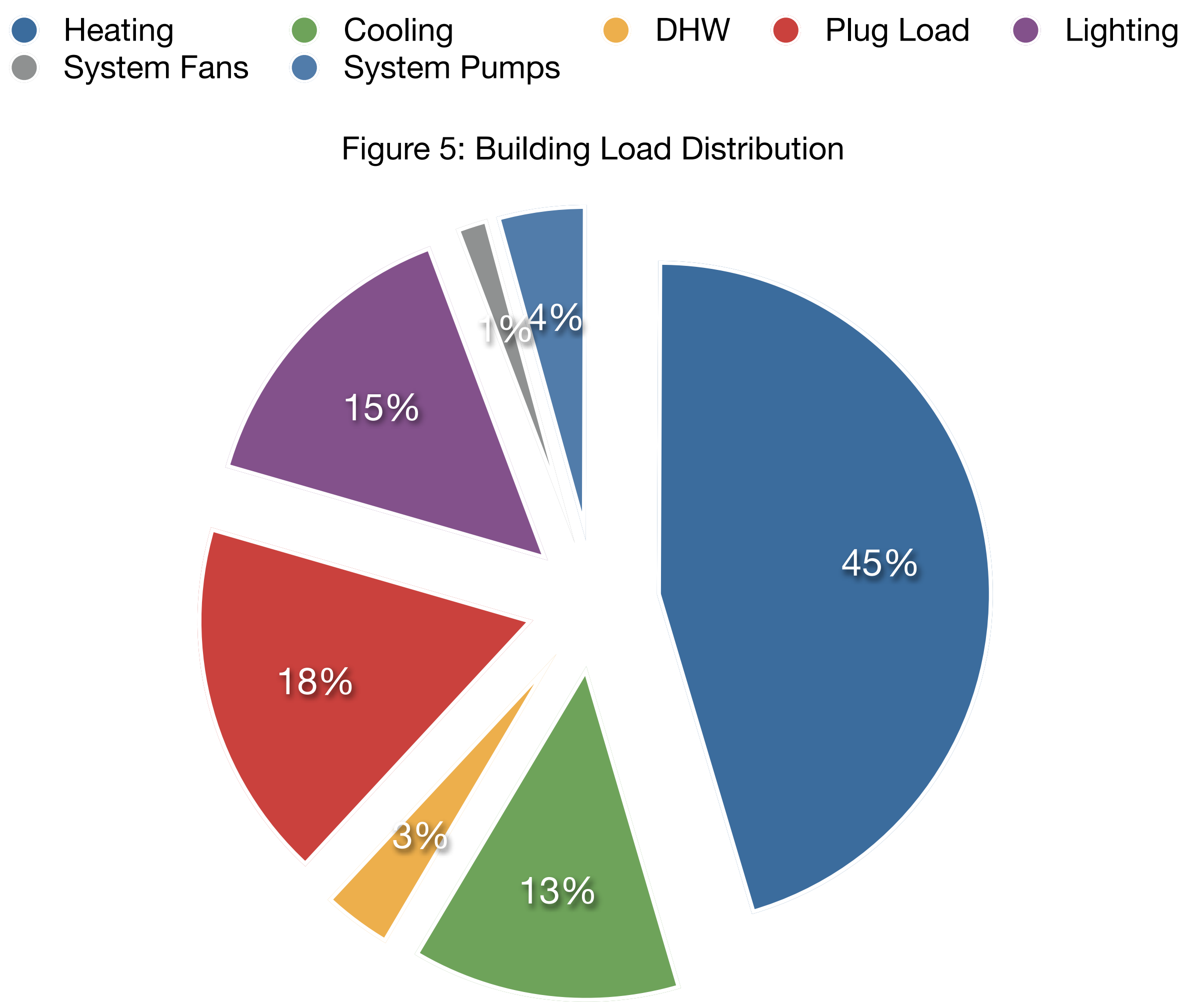

Figure 5: Building Load Distribution

Building Emission Rates

Emissions rates were calculated base on the total energy consumption of BBH. BBH is located in the Eastern Region according to the National Renewable Energy Laboratory (NREL) shown in Figure 6 below. The amount of pollutant per kWh of electricity and per ton of coal was obtained from the NREL Energy and Emissions Report.

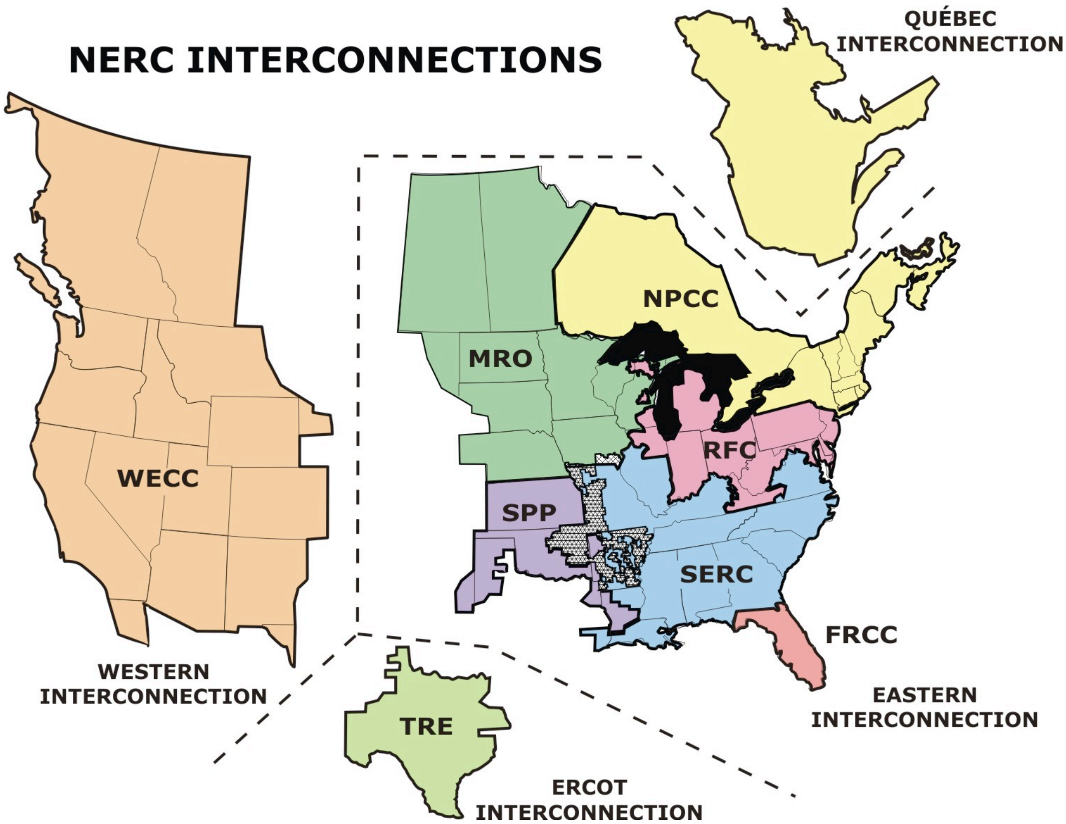

Figure 6: *NREC Interconnections*

Table 2.7: Annual Pollutant from Electrical and Cooling Load			
Pollutant	**Lb of Pollutant per kWh of Electricity**	**kWh of Electricity per Year**	**Total Amount of Pollutant per Year (lbs)**
CO_2	1.64	780291	1279677
Nox	0.003		2341
Sox	0.00857		6687
PM10	0.0000416		32
Total lbs of Pollutant	-	-	1288738

The PSU west campus steam plant was assumed to be a commercial coal fired boiler using bituminous coal.

Table 2.8: Annual Pollutant from Steam Consumption (Coal Fuel)			
Pollutant	**Lb of Pollutant per Ton of Coal**	**Tons of Coal Consumed**	**Total Amount of Pollutant per Year (lbs)**
CO_2	5260	156	820560
Nox	11.5		1794
Sox	3.32		518
PM10	4		624
Total lbs of pollutant	-	-	823496

Table 2.7 and 2.8 above show the amount of CO2, Nox, Sox and particulate matter (PM10) produce from the combustion process use to generate electricity for the electrical demand and steam for the steam demand, respectively. Comparing the pounds of pollutant per kWh and ton of coal, you can see the low efficiency in the process of generating electricity. As shown above in Figure 5, the heating load dominates all other loads in the building and this load is met via steam supply. The process of converting the energy in coal to heat in steam for building use is much higher than that of electricity generation and distribution. On the contrary, coal as a fuel is very dirty and you can see that the total pounds of pollutant generate by coal in less than that produced in the process of generating electricity but the particulate matter generated from producing steam is almost 20 times greater than the amount generated by producing electricity.

References

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NREL. (2007). *Source Energy and Emissions Factors for Energy Use in Buildings.* Midwest Research Institute: National Renewable Energy Laboratory.

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Appendix

See attached spreadsheets.

Pollutant Calculations						
	Heating		DHW		Total	
Specific Heat of Liquid Water (BTU/ LbF)	1		1		1	
Specific Heat of Steam (BTU/Lb)	1300		1300		1300	
Heat of Vaporization	1000		1000		1000	
Ti(F)	57		57		57	
Coal Heat Capacity (BTU/Lb)	13600		13600		13600	
Boiler Efficiency	0.60		0.60		0.60	
Heating BTU's	2364136000		173522000		2537658000	
Lb Steam	1818566.1538	1818.5661538	133478.46154	133.47846154	1952044.6154	
Lb Coal	173833.52941		12758.970588		186592.5	
Tons of Coal	144.86127451		10.63247549		155.49375	
Tons of Coal/ 1000lb of Steam	0.0796568627					
Lbs CO2/Ton Coal	5260	761970.30392	5260	55926.821078	5260	817897.125
Lbs Nox/Ton Coal	11.5	1665.9046569	11.5	122.27346814	11.5	1788.178125
Lbs Sox/Ton Coal	3.32	480.93943137	3.32	35.299818627	3.32	516.23925
Lbs PM10/ Ton Coal	4	579.44509804	4	42.529901961	4	621.975

Biobehavioral Health Building			
Sim Software		Designbuilder - EnergyPlus	Source/Assumption
Activity	**Occupant Density (P/SF)**	0.009	Building Average
	DHW Consumption rate (gal/SF/day)	0.007	Default
	Heating Setpoint (F)	70	OPR
	Heating Set Back (F)	60	OPR
	Cooling Setpoint (F)	75	OPR
	Cooling Set Back (F)	85	OPR
	Fresh air (CFM/SF)	0.147	Occupied OA Average from Cd's
	Computer Gain (W/SF)	0.2	Default
	Office Equipment Gain (W/SF)	2	Assumed Receptacle Equipment Load (All Spaces)
Construction	**External Walls (U-Value [BTU/hSFF])**	0.081	Tech 1
	Flat Roof (U-Value [BTU/hSFF])	0.047	Tech 1
	Pitched Roof (Unoccupied) (U-Value [BTU/hSFF])	0.047	Tech 1
	Internal Partitions (U-Value [BTU/hSFF])	0.576	Composition
	Floors (U-Value [BTU/hSFF])	0.578	Composition
	Airtightness (ac/h)	0.5	Default
Openings	**Glazing Type (U-Value [BTU/hSFF])**	0.423	Assumption
Lighting	**Lighting Density (W/SF)**	1	90.1 = 1.2 W/SF, Takeoff = 0.6W/SF
	Luminaire Type	Recessed	Lighting Schedule (Average for all spaces)
HVAC	**Template**	VAV with Terminal Reheat	Cd's
	System Availability	Classroom: 7am-11pm, All Other Spaces: 7am-8pm	OPR
	Night Cycle Control	Stay Off	Cd's
	Fan Efficiency (%)	80	Takeoff
	Fan Placement	Blow Through	Cd's
	Part-Load Power Coefficients	VFD	Cd's
Heating	**Fuel**	Waste Heat	Modeled Approach
	Design Margin	1	Assumption
	Heat Generation CoP	1	Modeled Approach
	Distribution Losses (%)	5	Default
	Coil Type	Hot Water	Cd's
	Off Coil AIr Temp Setpoint (F)	57	Cd's
	Heating Coil setpoint Reset Type	Outdoor Air Temperature Reset	Cd's
	Reheat Coil Type	Hot Water	Cd's
Cooling	**Fuel**	Waste Heat	Default
	Design Margin	1	Default
	Chiller CoP	1	Default
	Condenser Type	Water Cooled	Loop properties
	Distribution Losses (%)	5	Default
	Coil Type	Chilled Water	Cd's
	Cooling Coil Setpoint (F)	55	Cd's
	Cooling Coil Setpoint Reset Type	Outdoor Air Temperature Reset	Cd's
DHW	**Type**	Instantaneous DHW Only	Modeled Approach
	DHW CoP	1	Modeled Approach
	Fuel	Waste Heat	Modeled Approach
	Delivery Temp (F)	170	Cd's
	Mains Supply Temperature (F)	57	Assumed Ground Temp

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LEED-NC v2.2 EAc1

		Proposed Building Variable	Baseline Building Variable (ASHRAE 90.1-2004 Appendix G limit)	Referenced Standard
Sim Software		Carrier HAP v4.4	equal to proposed	
Weather	Design Day	90 DB/74 WB summer 0 DB/0 WB winter	equal to proposed	ASHRAE 90.1-2004, Table D-1
	Annual Sim	Erie, Pennsylvania (TM2)	equal to proposed	USA_PENN_ERIE_TMY2.HW1
	Climate Zone	5A	equal to proposed	ASHRAE 90.1-2004, Table B-1
Building Envelope	Walls	Above Grade: Brick on Block Wall, board insul, U=0.066 (R=15.05)	Above Grade: Steel-Framed Assembly U=0.084 (R=12)	ASHRAE 90.1-2004, Table 5.5-5 and Table G3.1 requirements
		Below Grade: 16-inch concrete, board insul, U=0.039 (R-25.49)	Below Grade: Assembly C=1.14 (U=0.58, R=1.72)	
	Roof	Vegetated Roof, U=0.023 (R=43.4), Reflectivity=0.61 Hip Roof with R-24 board insul over equipment room, U=0.023 (R=43.4), Refelectivity=0.61	Insulation Entirely Above Deck Assembly U=0.063 (R=16), Reflectivity=0.30, Built-up roof	
	Floor	Unheated Slab on Grade=6 in concrete, no insulation, F=0.730, C=0.93 (U=0.52, R=1.92) (2-foot wide, R-10 insul @ perimeter not modeled - small impact)	Unheated Slab on Grade=5 in concrete, no insulation, F=0.730, C=1.14 (U=0.58, R=1.72)	
	Fixed Windows	Double pane, low-e U=0.29, SHGC=0.32, SC=0.37	Metal Frame with Thermal Break, Double Pane Clear, Operable U=0.57, SHGC=0.39, SC=0.453, VLT=0.73	
	Window Area	Per plans, 29%	equal to proposed	
	Window Shading	None	None	
	External Shading	None	None	
	Skylights	None	None	
	Skylight Area	None	None	
Internal Loads	People	843	equal to proposed	
	Connected Lighting Power	1.0 W/sf - All spaces	1.0 W/sf - All spaces	ASHRAE 90.1-2004, Table 9.5.1
	Daylighting Estimated Power	Not Modeled	None	
	Other Lighting Control Credits	Not Modeled	None	
	Task Lighting Power Density	Not Modeled	None	
	Receptacle Equipment Power	2.0 W/sf - All spaces	equal to proposed	ASHRAE 90.1-2004 User Manual, Table G-B
	Infiltration	Not Modeled	equal to proposed	
HVAC Equipment Efficiency	Primary HVAC System Type	Variable Air Volume with reheat	System #7 - Packaged rooftop VAV with reheat	ASHRAE 90.1-2004, Table G3.1.1
	Other HVAC System Type	None	None	
	Fan Supply Volume	Variable Volume: Classroom: 7800 CFM SA, 3200 CFM OA Conference: 5900 CFM SA, 2000 CFM OA Core: 27,500 CFM SA, 5500 CFM OA Core Offices: North Offices: 9200 CFM SA, 3300 CFM OA South Offices: 8200 CFM SA, 1100 CFM OA	Variable Volume, Based on 20F Temperature Difference	ASHRAE 90.1-2004, Table G3.1.2.9 and G3.1.2.8 requirements
	Fan Power	Classroom: Conference: Core: Core Offices: North Offices: South Offices:	<20,000CFM: BHP=24+(CFM-20000)x0.0012 20,000CFM+: BHP=24+(CFM-20000)x0.001125	ASHRAE 90.1-2004 Table G3.1.2.9 requirements
	TERMINAL UNITs	*(VAV boxes)*		
	Heating Coil Setpoint	90F	90F	
	Minimum Airflow	0.4 CFM/sf	0.4 CFM/sf	ASHRAE 90.1-2004, G3.1.3.13 requirements
Con trol Strategy	Zone Setpoints	75 DB Occ, 85 DB Unocc Cooling 70 DB Occ, 60 DB Unocc Heating	equal to proposed	
	Cooling Coil Setpoint	55F	55F (for 20F delta)	ASHRAE 90.1-2004, G3.1.2.8 requirements
	Heating Coil Setpoint	53F	53F	
	Supply Air Temp Control	Temperature reset by greatest zone up to 65F	Temperature reset by greatest zone up to 65F	ASHRAE 90.1-2004, G3.1.3.12 requirements
	Demand Controlled Ventilation	100ppm min-delta, 700ppm max-delta, 400ppm OA	None	
	Economizer Control	Integrated enthalpy control, 75F upper cutoff	None	ASHRAE 90.1-2004, Table G3.1.2.6
	Energy Recovery	None	None	ASHRAE 90.1-2004, G3.1.2.10 requirements
Domestic Water Htg	Domestic Water Heating Equipment	XXX Instantaneous gas-fired water heaters, 285 MBH peak.	equal to proposed	
PV	PV	None	None	None
Misc Energy	Ext Lighting	XXX 6.0 KW	equal to proposed	
	Elevator	XXX 65 KW	equal to proposed	
Energy Cost	Electricity	$0.09387 / KWH, $1.09 / KW	equal to proposed	PSU Provided Electric Rate for 2011/12
	Chilled Water	$0.22 / ton-hour	equal to proposed	PSU Provided District Chillled Water Rate for 2011/12
	Steam	$24.50 / 1000 lb	equal to proposed	PSU Provided District Steam Rate for 2011/12
Annual Energy Cost		113,800	159,074	**28.5%, 6 LEED Points**
Building Total SF		80,102	80102	
$/SF		1.42	1.99	

		Alternate Proposed Building Variable	Original Proposed Building Variable	Impact of Alternate
ALT	Energy Recovery	75% efficient energy wheel, 0.4 KW input, operates year-round, All units but Core	None	**32.6%, 7 LEED Points**
	Annual Energy Cost	$107,170	$113,800	**$6,630**
ALT-A	Energy Recovery Classroom Only	75% efficient energy wheel, 0.4 KW input, operates year-round	None	**29.8%, 6 LEED Points**
	Annual Energy Cost	$111,678	$113,800	**$2,122**
ALT-B	Energy Recovery Core Only	75% efficient energy wheel, 0.4 KW input, operates year-round	None	**28.0%, 6 LEED Points**
	Annual Energy Cost	$114,501	$113,800	**-$701**
ALT-C	Energy Recovery Core Offices Only	75% efficient energy wheel, 0.4 KW input, operates year-round	None	**28.8%, 6 LEED Points**
	Annual Energy Cost	$113,190	$113,800	**$610**
ALT-D	Energy Recovery Conference, North, South Only	75% efficient energy wheel in separate Energy Recovery Ventilator, 0.4 KW input, operates year-round	None	**30.9%, 6 LEED Points**
	Annual Energy Cost	$109,895	$113,800	**$3,905**