STEM Wing Addition

Brookline High School

Design Development Energy Analysis Report

Revision-1

Image ©: William Rawn Associates, Architects, Inc.

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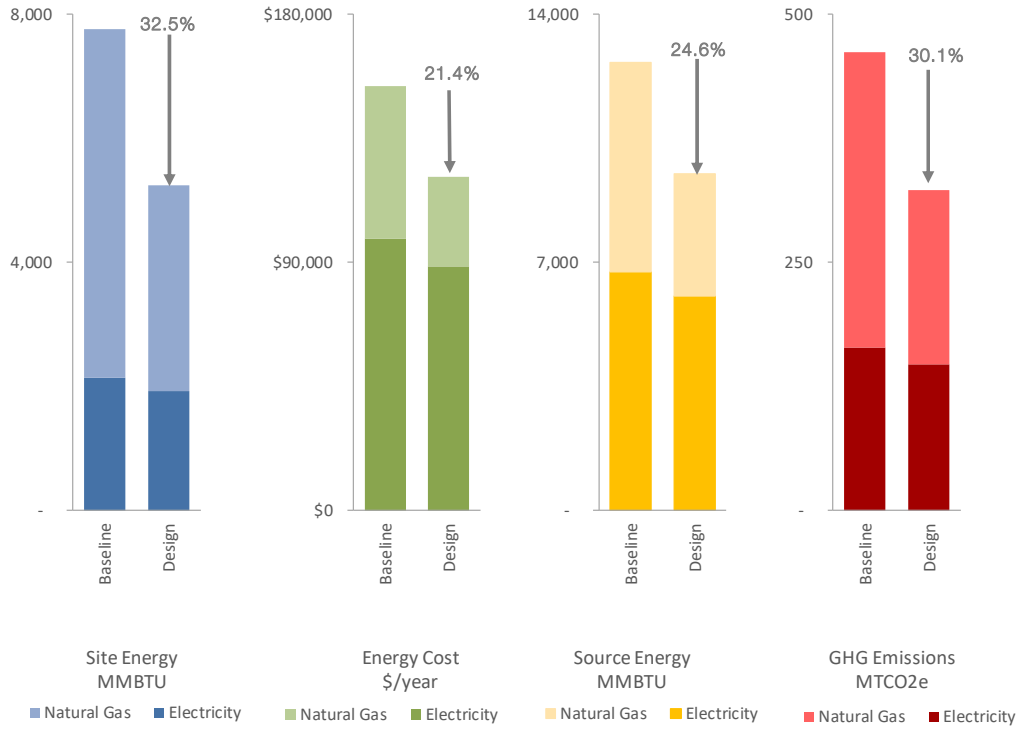
Executive Summary

The project consists of the addition of a three-story new STEM Wing to the existing Robert's Wing at the Brookline High School campus in Brookline, MA. The approx. 68,345 GSF addition will include a new culinary arts kitchen/café, science classrooms, biology and chemistry labs, maker spaces, teacher planning areas and collaborative spaces. The project scope also includes a below grade floor for back-of-house and electrical/mechanical support spaces. The proposed addition will connect to the existing building at two locations - at the stair near the cafeteria and auditorium and at the connecting corridors at the central administration, library and the academic building.

The Green Engineer (TGE) has performed building performance analysis to compare the design with a LEED baseline, modeled in accordance with ASHRAE 90.1-2010, Appendix G. The results of the modeling indicate that the as-designed building is expected to show total energy-cost savings of **21.4%** compared to the Baseline. The percentage annual site and source energy savings are estimated at **32.5%** and **24.6%,** respectively. Additionally, the greenhouse gas (GHG) emissions for the proposed design are estimated at **323.2** MTCO2e, an approximately **30.1%** reduction from the Baseline emissions.

Standard LEEDv4 compliance path uses energy cost metrics for credit achievement. This project has a potential to earn **8 LEED** points based on annual energy cost savings. Based on the LEED v4 pilot alternative compliance path (ACP)[1], that allows using alternate metrics such as source energy, GHG emissions, etc., for documenting performance improvement, the estimated savings for the project are **27.3%** which is equivalent to **11 LEED for Schools (v4)** points. Summaries of these results are presented in the following sections.



[1] Source: LEEDv4 BD+C Alternate Energy Performance Metric

I. Description of Alternatives

ASHRAE 90.1-2010 Baseline: The building as-designed, except that the envelope constructions, mechanical equipment, and lighting meet the minimum requirements of ASHRAE 90.1-2010.

Design Case: The building as-designed. The design inputs are based on the Design Development Pricing Set drawings and documents, and information provided by the design team. This design option assumes Solarban 60 glazing at east façade, north curtain wall and south curtain wall, as indicated on the drawings. Solarban 70XL glazing is assumed on all other locations.

Every effort has been made to use reasonable assumptions for building components and systems where details were not available.

Design Case-Alternate Options: The following additional design options have been assessed.

Option1- Alt Glazing: The building as-designed. Solarban 60 glazing assumed in lieu of Solarban 70XL.

Option 2- Alt Roof Insulation: The building as-designed. A 6" minimum polyisocyanurate insulation (U-0.028) in lieu of 8" polyisocyanurate specified in the Design Case.

Option 3- Alt Glazing and Roof Insulation: The building as-designed. Solarban 60 assumed in lieu of Solarban 70 XL and 6" minimum polyisocyanurate roof insulation in lieu of the 8" option.

Further, the team was interested in how much of an impact the extended hours of operation (evenings, Saturdays and summer) for the level-1 public areas i.e. bathrooms, maker space, and culinary arts classroom would have on the annual energy use, so a version of the model was run in which the school is only used for academic purposes (Monday-Friday, 8:00 a.m. – 3 p.m.). Details for occupancy and hours of operation included in the energy model are provided in Section V of this report.

Simulation results for the extended academic schedule as well as the alternate schedule (standard school hours) are provided in Section III of this report. As requested by the design team, the design options summarized above have been assessed for the alternate operating schedule as well.

Please refer to Appendix-A for detailed model inputs.

II. Energy Conservation Measures

The following ECM's have been identified for the project:

- Improved envelope assemblies and fenestration
- Reduced interior lighting through use of high-efficiency LED fixtures
- High efficiency 100% outside air VAV energy recovery units
- The design includes partial cooling for all areas, except the faculty spaces that have full air-conditioning. This results in a lower overall energy use for the project.
- Supply air temperature reset

- Perimeter finned tube radiators (FTR's) and radiant panels with hot water heating. Perimeter FTR's meet space loads during unoccupied periods eliminating the need for RTUs to cycle on at night and unoccupied periods.
- Unoccupied air-change in lab spaces lower than ASHARE 90.1 2010 requirements
- High efficiency boilers and optimized hot water loop parameters
- High efficiency air-cooled chiller and optimized chilled water loop parameters
- High efficiency VRF-HPs in faculty and office spaces

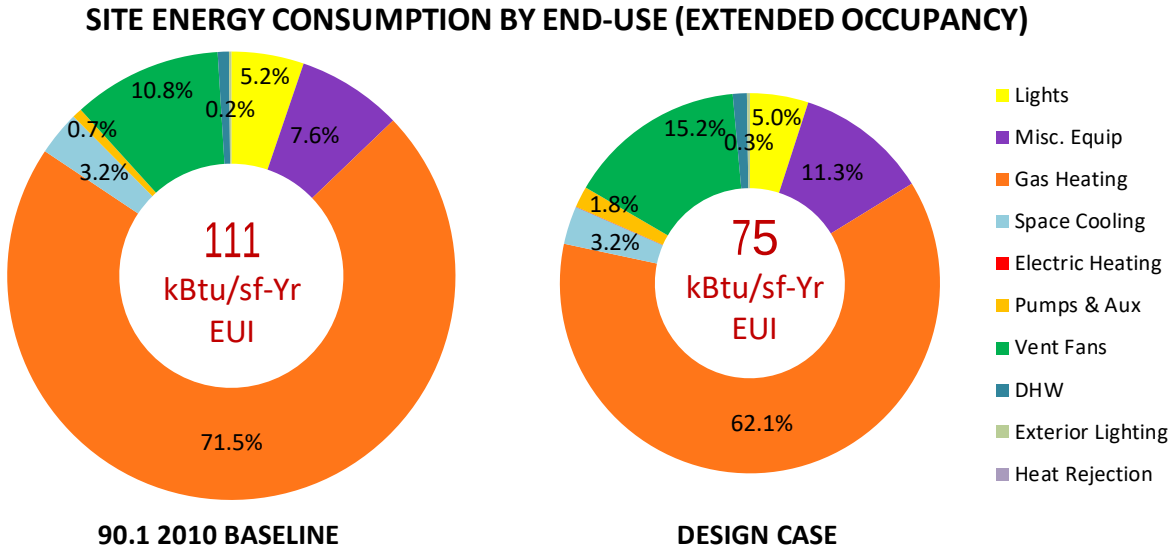
III. Simulation Results

a. Baseline Schedule – Extended Occupancy

Following are the simulation results obtained from the energy model iterations. The annual energy use and cost savings for the proposed design are based on energy efficiency strategies incorporated in the design to reduce the energy consumption in the building. The following tables summarize energy use and cost results for the Baseline and the Proposed Design based on extended hours of operation. Also included are the estimated source energy savings and GHG emissions reduction for the Design compared to the Baseline.

Site Energy Use Savings (MMBtu/Yr)													
Description	Lights	Misc. Equip	Gas Heating	Space Cooling	Electric Heating	Pumps & Aux	Vent Fans	DHW	Exterior Lighting	Heat Rejection	Total	% Savings	EUIs
LEED Baseline	405.5	589.1	5,546.0	247.3	-	54.7	833.7	62.0	13.4	-	7,751.7	-	111
Design Case	260.4	589.1	3,251.0	169.8	1.9	93.6	793.6	62.1	13.4	-	5,234.9	32.5%	75
Option 1- Alt Glazing	260.4	589.1	3,178.0	168.0	1.7	92.2	793.7	62.1	13.4	-	5,158.6	33.5%	73.9
Option 2 - Alt Roof	260.4	589.1	3,267.0	169.5	1.9	93.7	793.6	62.1	13.4	-	5,250.7	32.3%	75.2
Option 3 - Alt Glazing + Alt Roof	260.4	589.1	3,195.0	167.8	1.7	92.0	793.8	62.1	13.4	-	5,175.3	33.2%	74.1

Energy Use, GHG Reduction and Cost Summary						
Description		LEED Baseline	Design Case	Option 1- Alt Glazing	Option 2 - Alt Roof	Option 3 - Alt Glazing + Alt Roof
Annual Site Energy Summary						
Electricity	kWh	628,104	563,087	562,121	563,029	562,033
Natural Gas	MMBtu	5,608	3,313	3,240	3,329	3,257
Total Site Energy use	MMBtu	7,752	5,235	5,158.6	5,250.7	5,175
Annual Energy Cost Reduction						
Electricity	$/year	$98,612	$88,405	$88,253	$88,396	$88,239
Natural Gas	$/year	$55,463	$32,767	$32,045	$32,925	$32,213
Total Energy Cost	$/year	$154,075	$121,171	$120,298	$121,320	$120,452
	Site Energy Cost Savings (%)		21.4%	21.9%	21.3%	21.8%
Annual Source Energy Reduction						
Total Source Energy use	MMBtu	12,039	9,079	8,995	9,094	9,011
	Source Energy Savings (%)		24.6%	25.3%	24.5%	25.2%
Green House Gas (GHG) Reduction						
Total GHG Emissions	MTCO2e	462.1	323.2	319.0	324.0	319.9
	GHG Reduction(%)		30.1%	31.0%	29.9%	30.8%



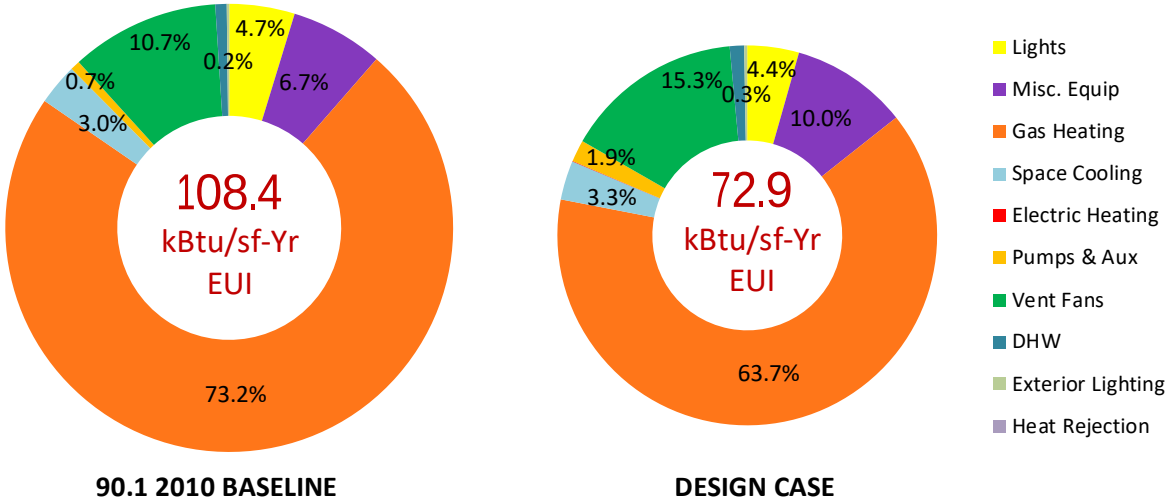
b. Alternate Schedule – Standard School Hours Only

The following tables summarize energy use and cost results for the Baseline and the Proposed Design with standard hours of operation i.e. Monday - Friday 8a.m. – 3p.m. The school is assumed to remain closed on weekends and during summer and winter breaks. Also included are the estimated source energy savings and GHG emissions reduction for the Design compared to the Baseline.

Site Energy Use Savings (MMBtu/Yr)													
Description	Lights	Misc. Equip	Gas Heating	Space Cooling	Electric Heating	Pumps & Aux	Vent Fans	DHW	Exterior Lighting	Heat Rejection	Total	% Savings	EUIs
LEED Baseline	357.7	506.6	5,537.0	225.8	-	52.9	812.7	62.0	13.4	-	7,568.1	-	108.4
Design Case	224.0	506.6	3,242.0	169.3	2.2	94.5	776.8	62.1	13.4	-	5,090.9	32.7%	72.9
Option 1- Alt Glazing	224.0	506.6	3,165.0	165.5	1.8	92.7	776.7	62.1	13.4	-	5,007.8	33.8%	71.7
Option 2 - Alt Roof	224.0	506.6	3,258.0	169.2	2.2	94.3	776.8	62.1	13.4	-	5,106.6	32.5%	73.2
Option 3 - Alt Glazing + Alt Roof	224.0	506.6	3,182.0	165.3	1.8	92.4	776.8	62.1	13.4	-	5,024.4	33.6%	72.0

Energy Use, GHG Reduction and Cost Summary						
Description		LEED Baseline	Design Case	Option 1- Alt Glazing	Option 2 - Alt Roof	Option 3 - Alt Glazing + Alt Roof
Annual Site Energy Summary						
Electricity	kWh	576,946	523,532	521,745	523,445	521,628
Natural Gas	MMBtu	5,599	3,304	3,227	3,320	3,244
Total Site Energy use	MMBtu	7,568	5,091	5,007.8	5,106.6	5,024
Annual Energy Cost Reduction						
Electricity	$/year	$90,581	$82,195	$81,914	$82,181	$81,896
Natural Gas	$/year	$55,374	$32,678	$31,916	$32,836	$32,084
Total Energy Cost	$/year	**$145,955**	**$114,872**	**$113,830**	**$115,017**	**$113,980**
	Site Energy Cost Savings (%)		21.3%	22.0%	21.2%	21.9%
Annual Source Energy Reduction						
Total Source Energy use	MMBtu	11,506.8	8,664.4	8,568.9	8,680	8,585
	Source Energy Savings (%)		24.7%	25.5%	24.6%	25.4%
Green House Gas (GHG) Reduction						
Total GHG Emissions	MTCO2e	448.2	312.4	307.8	313.2	308.7
	GHG Reduction(%)		30.3%	31.3%	30.1%	31.1%

SITE ENERGY CONSUMPTION BY END-USE (STANDARD OCCUPANCY)



90.1 2010 BASELINE **DESIGN CASE**

IV. Discussion of Results:

- The design includes several energy efficiency measures that provide annual energy use savings for the project. Interior lighting and space heating and space cooling are the three largest end-uses contributing towards overall savings for the project.

- The Site EUI for the design, based on the current model inputs, is estimated at 75 kBtu/sf-yr. The higher EUI compared to a typical high school is due to the inclusion of chemistry and biology labs in the design. The GHG emissions for the Proposed Design are estimated at 323.2 MTCO2e, an approximately 30% reduction from the Baseline GHG emissions estimated at 462 MTCO2e.

  This preliminary analysis shows that pursuing the pilot LEED ACP and using alternate performance metric such as source energy, GHG emissions, etc., to document savings can potentially provide up to 11 LEED-Sv4 points for this project. *Note that achieving additional credit using this ACP requires project teams to calculate and document all required energy metrics and is subject to approval by the GBCI.*

- Based on the current AHU capacities for the 100% OA RTU's, it appears that the non-lab spaces are sized for OA rates higher than the 62.1 minimum allowance. The design case model accounts for a small penalty from excess ventilation in corridors, common areas and other non-lab support spaces. As the design outdoor air sizing for these spaces becomes available, the energy models will be updated to accurately capture ventilation in each zone.

- Note that the EUI for this project is predicted higher than a typical high-school project but is lower than typical high intensity laboratory projects.
  - The design includes partial cooling for all areas except the faculty spaces that have full air-conditioning. This results in a lower overall energy use for the project.
  - Lab spaces account for only about 40% of the total project area.
  - Lab spaces are used only 8a.m. to 3p.m during the school academic year and remain closed in the summer.
  - Fume hoods are expected to be in use for only 2 hours per week.

- Alternate Building Operation Schedule: The iteration of the energy model in which hours of operation are limited to academic hours only shows annual energy use of 5,091 MBtu/year compared to the 5,235 MBtu/year for the anticipated extended operating hours. The EUI for the alternate occupancy schedule equates to 72.9 kBtu/SF-yr, compared to the anticipated 75 kBtu/SF-yr estimated for the anticipated use.

- The alternate glazing iteration shows an approximately 1% reduction in annual energy use for both schedule options analyzed. The two glazing options modeled have similar u-values but differ in their SHGC. The building is heat load driven and full cooling is not being provided for majority of spaces. Higher SHGC for Solarban 60 helps in reducing the overall heating energy use for the building. The alternate roof option, with reduced insulation results in a small energy penalty of less than 0.5%.

V. Modeling Methodology

This phase of the energy modeling, based on the Design Development pricing set dated 30th November 2018, and information provided by the design team, evaluates the performance of the proposed design against an ASHRAE 90.1-2010 compliant Baseline building for LEEDv4. The modeling was performed in accordance with ASHRAE Standard 90.1-2010, Appendix-G guidelines.

The purpose of presenting this information is to provide a gauge for the project in terms of energy performance and an opportunity for the design team to review the energy model assumptions for accuracy. The overall energy savings and estimated annual energy consumption for the project is likely to change as the design gets further refined, and the energy model inputs are reviewed and finalized.

The annual energy cost estimates are based on energy modeling results, using eQUEST version 3.65 modeling software. The eQUEST software uses DOE-2 calculation engine to estimate annual energy consumption by simulating a year of building operations based on a typical weather year and user inputs.

The geometry of the building is based on the AutoCAD floor plans, except that window positions are simplified based on a percentage glazing in each zone and exposure. It is important to keep in mind the limitations of energy models when reviewing this information. The results are based on the current design assumptions and utility rates described within this report.

Further, energy consumption is highly dependent on weather conditions and the actual operating schedule of the building. The numbers generated will not necessarily be an accurate projection of actual energy costs but should serve as an accurate comparison between alternatives.

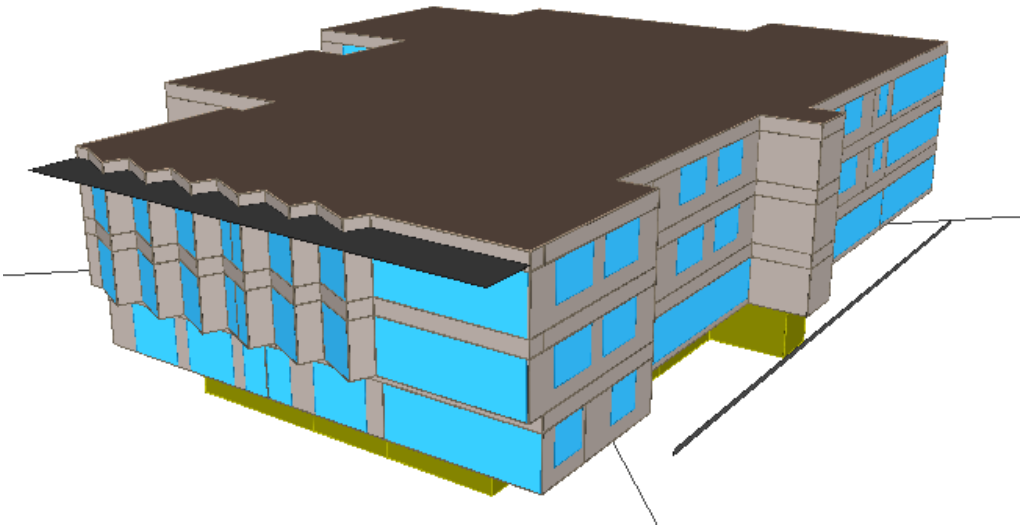


Image 1: STEM Wing Addition – Energy Model 3D View

Occupancy and building operation:

The estimated annual energy use is based on the following hours of operation:

Academic School Year: Building in Full Use
School Day: 8am – 3pm
After hours: 3pm – 10pm (only public areas, bathrooms, makerspace, and culinary arts classroom are available for use – all labs are closed)
Saturdays: Partial use between 8am & 3pm (only 1st floor spaces noted above)
Kitchen: Operational from 8am-3pm during the academic year; closed in the evenings
Sundays: Closed
Holidays, Winter Break, Spring Break: Closed

Summer: Partial Building in Full Use
Mon-Sat: Partial Use between 8am - 3pm (only 1st floor spaces noted above)
Sundays: Closed
Kitchen: Closed in the summer

The annual energy use for the following Alternate Schedule has also been included in the result summary.

Academic School Year Only: Building in Full Use
School Day: 8am – 3pm
All other dates/times (including summer): Closed

Utility Rates:

The following EIA State Average Rates for electricity and natural gas have been used for estimating annual energy cost savings for the project:

- Electricity: $ 0.157 /kWh (2017 EIA Average for MA)
- Gas: $9.89 /MBTU (2017 EIA Average for MA)

VI. LEEDv4 Pilot ACP: Alternative Energy Performance Metric

Under the LEED v4 Rating System project teams may use the pilot alternative compliance path (ACP) for documenting savings under the EA Optimize Energy Performance Credit. The intent of this ACP is to allow project teams to use performance metrics other than cost for documenting performance improvement. The ACP requires project teams to calculate and report a metric from each of the required categories:

- Site Energy Cost
- Source Energy
- Greenhouse gas emissions
- Time Dependent Valuation (TDV) Energy (if available)

The average percent savings of the two highest-performing metrics, using equal weighting, is then used to determine percentage energy savings for the project.

For this project, the average percent savings for the two highest-performing metrics i.e. greenhouse gas emission reduction and source energy use reduction are estimated at 27.3% which earns the project 11 LEED credit points.

Note that the following Energy Star Portfolio Manager GHG emissions factors were used for this analysis:

- Electricity: 0.0767 MTCo2e / MMBTU for New England
- Natural gas: 0.05311 MT Co2e /MMBtu (US Average)

APPENDIX-A: MODEL INPUT SUMMARY

The envelope, internal load assumptions and HVAC system inputs in the energy model are based on the drawings and documents available to us and inputs from the design team.

Brookline STEM Building: Design Development Model Inputs		
Project Area	68,345 SF	
Building Envelope	**Baseline Case (ASHRAE 90.1 2010)**	**Design Case**
Roofs	ASHRAE 90.1 2010, Table 5.5-5 (CZ 5A): Insulation entirely above Deck. R-20 c.i. Assembly U-Value: 0.048	Insulation entirely above Deck: R-45.6 c.i. (8" min Polyiso insulation @R 5.7/inch) Assembly U-Value:0.021
Walls - Above Grade	ASHRAE 90.1 2010, Table 5.5-6 (CZ 5A): Steel-framed Construction. R-13.0 + 7.5 c.i. Assembly U-Value: 0.064	Brick Veneer Wall: R-27.62 Effective R-Value Assembly U-0.036
Slab on Grade	Unheated, 6" slab on grade floor F-0.73	Modeled same as Baseline
Fenestration and Shading	**Baseline Case (ASHRAE 90.1 2010)**	**Design Case**
Vertical Glazing Description and WWR%	Curtain Walls and Punched Windows	Curtain Walls and Punched Windows
Vertical Glazing U-factor	ASHRAE 90.1 2010, Table 5.5-5 Metal Framing (CW) Assembly U-value: 0.45 Metal Framing (Punched): Assembly U-Value: 0.55	Solarban 60 + Kawneer 1600 Sys 3 Assembly U-0.39 Solarban 70XL + Kawneer 1600 Sys 3 Assembly U-0.39
Vertical Glazing SHGC	0.4	Solarban 60 SHGC - 0.38 Solarban 70XL SHGC - 0.27
Visual Light Transmission	0.9	0.7
Lighting and Equipment	**Baseline Case (ASHRAE 90.1 2010)**	**Design Case**
Lighting Power Calc Method	Building Area Method	Building Area Method
Lighting Power Density	0.99W/SF	0.63 W/SF Calculated based on DD Set dated 11/30
Occupancy Sensor		Yes
Daylight Dimming Controls	Included if required by ASHRAE 90.1 2010	Perimeter Zones: Stepped dimming to 70% and 35% of full power
Equipment Power Density	Same as design	Kitchen: 5.0 W/SF Office: 1.5 W/SF Chemistry Lab: 2.5 W/SF Biology Lab: 2.5 W/SF Cafeteria: 2.5 W/SF

HVAC - Air Side	Baseline Case (ASHRAE 90.1 2010)	Design Case
Primary HVAC Type	System #5: Packaged VAV with Reheat (DX/Purchased HTHW)	VAV with Reheat (air cooled chiller/ HTHW from boiler plant in adjacent building) RTU-1.1&1.2: Addition floors: B,1,2,3 RTU-2.1: Culinary Arts Kitchen
Secondary HVAC Type	Heated Only Systems serving mech/electrical, stairs, vestibules, etc. as applicable.	Mini-split AC/HP units serving lab-aid office, telecom room, elev. ctrl room. VRF units serving kitchen office, quiet work, faculty collab and dept. head office. Finned tube radiators (FT-1, FT-2): as shown on plans Radiant panels (RP-1): as shown on plans Cabinet unit heaters (CUH 1-4): vestibules, stairs, collaboration space.
Fan System Operation	Variable volume fans, 30% min turn-down or ventilation requirement, whichever is higher. Supply and return fans operate continuously whenever spaces are occupied and cycle to meet loads during unoccupied periods.	Variable volume fans. Supply and return fans operate continuously whenever spaces are occupied. Units never operate below 25% min turn-down setpoint. Perimeter Finned Tube Radiators and Radiant Panels meet loads during unoccupied periods.
Equipment Cooling Capacity	Cooling equipment capacities auto-sized and oversized by 15%.	RTU 1.1&2: 522.1 MBH total /198 Sensible (each) RTU 2.1 (CC-1&2): 1400 CFM each
Unitary Cooling Efficiency	Min DX Cooling Efficiency as per ASHRAE 90.1 2010	Air cooled chiller in design HPs and VRFs: DX
Total Heating Capacity and Efficiency	Heating capacities auto-sized and oversized by 25%. Heating source modeled as 80% Et natural draft boilers as per ASHRAE 90.1 requirements.	RTU 1.1&2: 1051MBH each RTU 2.1: 605.5 MBH Heating source modeled as 85% Et HW Boilers w/draft.
Outdoor Air Design Min Ventilation	Lab Spaces: Same as design Non-Lab Spaces: As per ASHRAE 62.1 allowance	RTU-1.1&1.2: 20,000 CFM each RTU-2.1: 7,800 CFM Lab Spaces: 6ACH occupied/2ACH unoccupied and 4ACH when occupied but chemicals are not in use. Non-Lab Spaces: Based on 100% OA AHU CFM capacity with 25% minimum turn down.

Fume Hoods	Modeled same as design	Fume Hoods: On/Off type, variable volume. Current iteration assumes 825 CFM exhaust when fume hood is turned on. Fume hoods modeled to operate on an average 2 hours per week.
Economizer	Economizer high-limit shutoff: 70F	Economizer high-limit shutoff: 70F
System Fan Power	As per ASHRAE 90.1 2010 Fan Allowance Pressure credit: Fully ducted return/exhaust (0.5 in w.c.); MERV 13 filter on OA (0.9 in w.c.); energy recovery (1.2 in w.c.); sound attenuation (0.15 in w.c.); exhaust system serving fume hoods (0.35 in w.c.).	RTU 1.1&1.2: Supply - 2 Fans 10,000 cfm each, 15.8BHP/20HP (1.27 w/cfm) Return - 2 Fans 10,000 cfm each, 10BHP/15HP (0.8 w/cfm) RTU 2.1: Supply 2 Fans 3900 cfm each, 3.22BHP/3.5 HP (0.688 w/cfm) Exhaust (GEF 1.1): 4.7 BHP/7.5 HP (0.475 w/cfm) HPs and VRFs in faculty spaces and individual offices
Supply Air	System design supply air flow rates based higher of a supply-air-to-room-air temperature difference of 20 degF, or min ventilation requirements.	RTU-1.1 & 1.2: 20,000 CFM each RTU-2.1: 7,800 CFM GEF 1.1: 8,100 CFM
Supply Air Temperature Reset Parameters	The air temperature for cooling shall be reset higher by 5F under minimum cooling load conditions	Included identical to Baseline
Exhaust Air Energy Recovery	50% Recovery Effectiveness, where applicable	RTU 1.1 &1.2: Enthalpy wheel, ~65% total recovery effectiveness. RTU 2.1: NA
Exhaust Fans	Modeled same as design	FEF 1.1 (Fume Hood): 6,340 CFM, 5.7BHP/7.5HP FEF 1.2 (Fume Hood): 5,770 CFM, 7.1BHP/7.5HP GEF 1.1 (Kitchen Hood): LEF 1.1 & 1.2 (Laser Cutter): 850CFM, 2BHP/3HP each TEF 1.1 (Toilet): 1200 CFM, 0.6BHP/0.75HP
HVAC - Water Side	**Baseline Case (ASHRAE 90.1 2010)**	**Design Case**
Number of Boilers	2 Natural Draft Boilers Thermal Efficiency: 80%	2 HW Boilers w/Draft Thermal Efficiency: 85%
Hot Water Loop Temperatures	180F; 50F dT	180F; 30F dT
HHW Loop Temp Reset Parameters	180F @ 20F outdoor, 150F @ 50F outdoor	Reset between max (180F) and min (140F) range based on zone reheat loads
Number of Primary HHW Pumps	One @ 19W/gpm	Two (2) HHWP 1.1 & 1.2; staged 200 gpm; 70 Ft head; 5bhp/7.5hp each VFD on pumps
Pump Speed Control	Riding the pump curve	VSD on Pumps
Number of Chillers	NA	One (1) 120 Ton Air-cooled Scroll Chiller Basis of Design: DAIKIN AGZ120E FL 10.3 EER/ IPLV 15.5 EER
Chilled Water Supply Loop Temp	-	42F

Chilled Water Loop Delta T	-	12F
Number of Primary CHW Pumps	-	Three (2+1 standby) CHWP 1.1-1.3; staged 125 gpm; 70 ft head; 2.96 bhp/5hp each VFD on pumps
CHW Loop Temp Reset Parameters		Reset based on Load *BMS resets discharge CHW temp up 1-deg every 10 minutes with a max reset of 3-deg until at least one control valve is 95% open. Once one valve reaches 100% the BMS resets CHW down by 1-deg every 10 minutes or when CHW reaches 42F.*
Number of Cooling Towers / Fluid Coolers	NA	NA (air-cooled chiller)