BROOKLINE HIGH SCHOOL EXPANSION

SCHEMATIC DESIGN SUSTAINABILITY OVERVIEW
APRIL 3, 2018

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PROJECT OVERVIEW, SCHEDULE, & PROCESS

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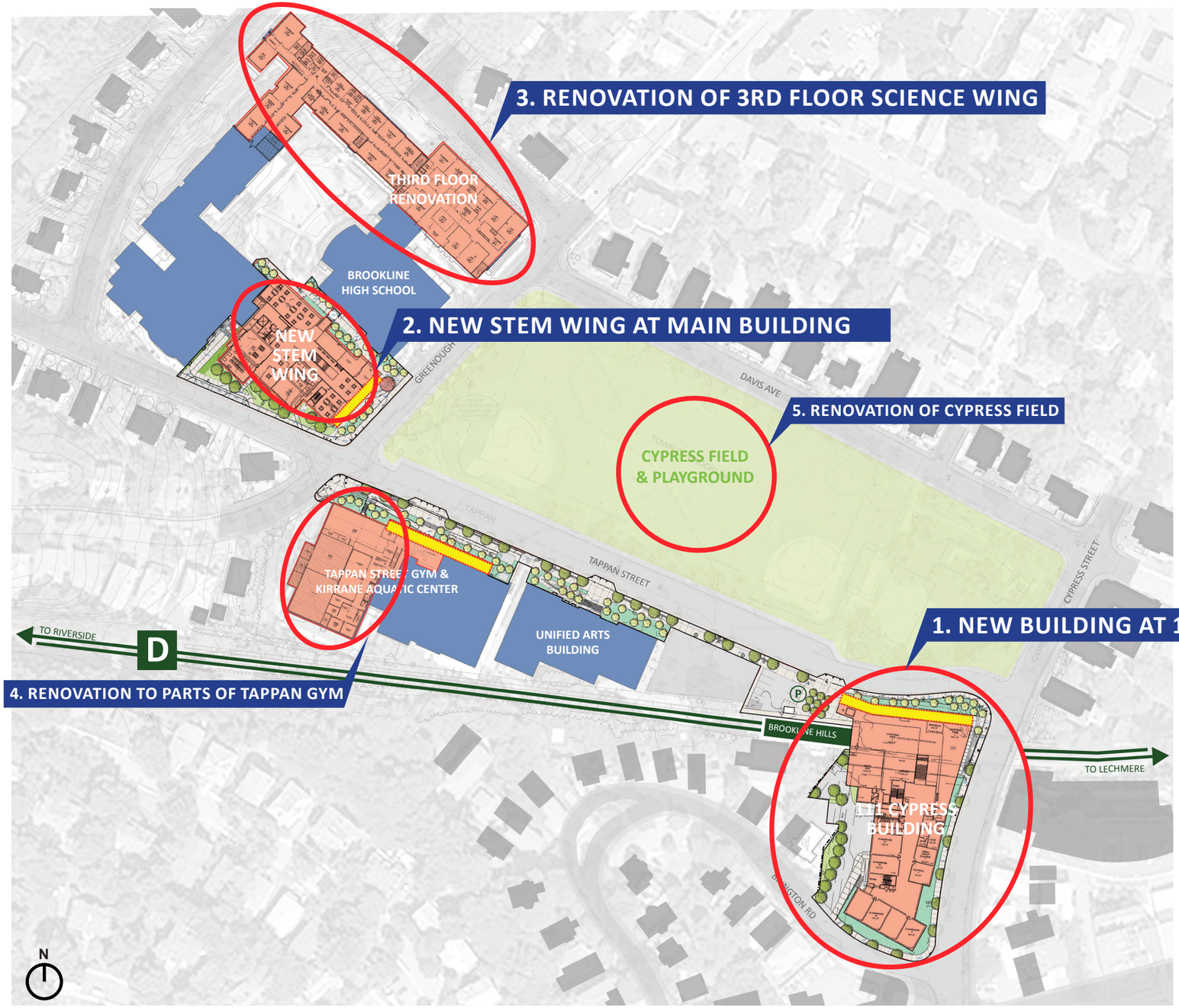
SCOPE OF BROOKLINE HIGH SCHOOL EXPANSION PROJECT



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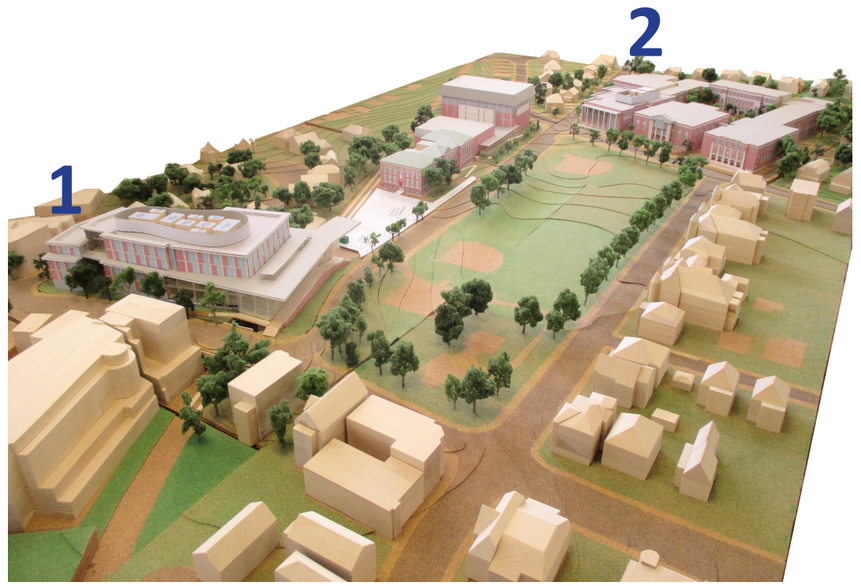
BROOKLINE HIGH SCHOOL EXPANSION: LEED PROJECTS



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SCHEDULE & PROCESS: SUSTAINABLE DESIGN

Prior to May 7, 2018 Override Vote

Schematic Design (SD)

STEP 1
- Building organization & massing approved by stakeholders
- Conceptual Box Energy Models
- HVAC Systems analysis and selection
- Energy Charette w/ MassSave

STEP 2
- Envelope design approved by stakeholders
- Schematic Energy Model
- Glass / Wall Ratio Options
- LEED Checklist

After May 7, 2018 Override Vote

Design Development (DD)
- Systems refinement & analysis
- Envelope refinement & analysis
- LEED Workshop w/ Town

Construction Documents (CD)
- Design Documentation
- Rebate Analysis
- LEED Design Submission
- Final Energy Model

Construction
- LEED Construction Submittals
- Commissioning

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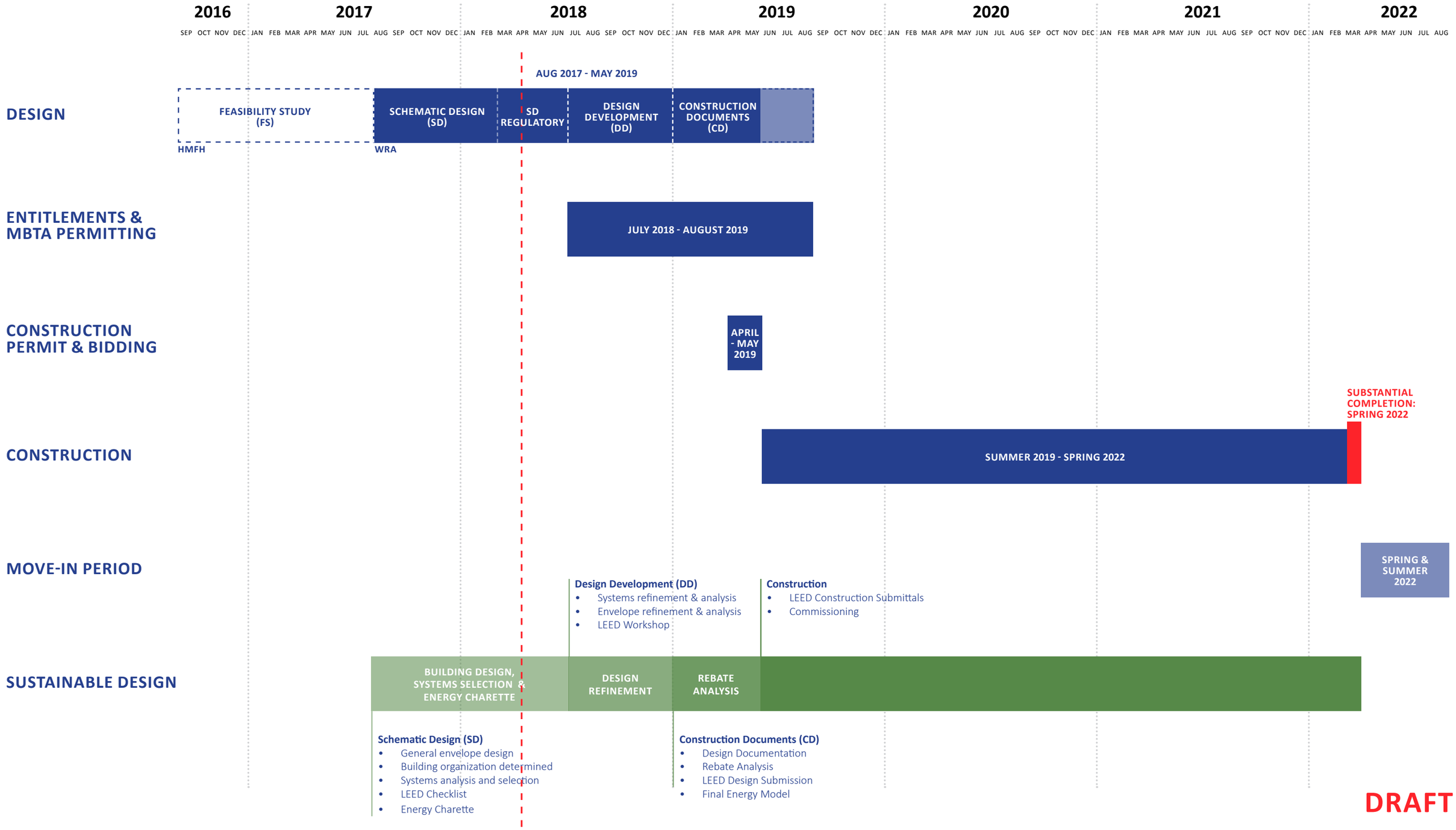
SCHEDULE & PROCESS

OVERALL SCHEDULE



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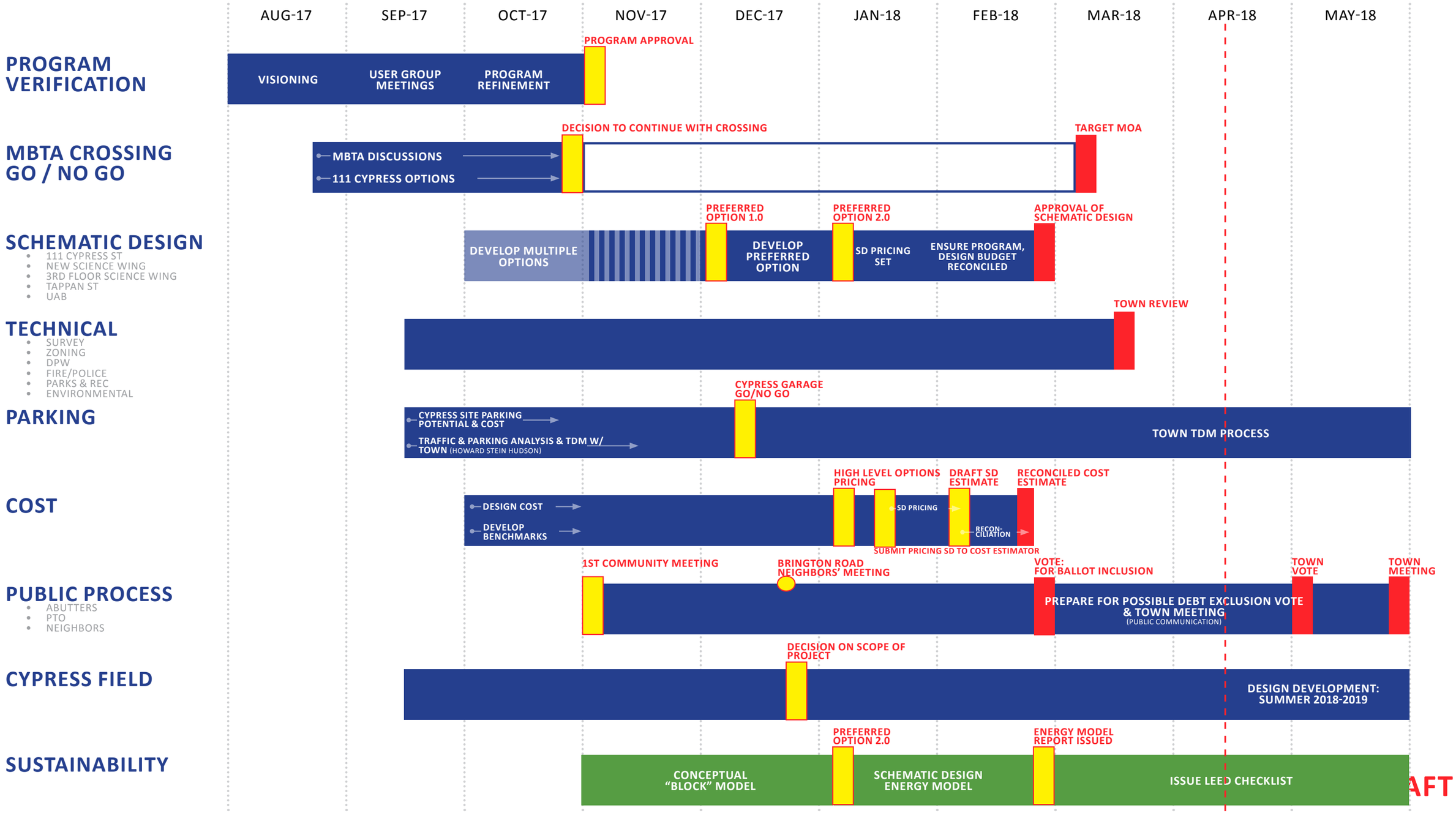
SCHEMATIC DESIGN (SD) SCHEDULE

8 PARALLEL TRACKS

SCHEDULE ON TRACK - MILESTONES MET SHOWN IN YELLOW:



PROJECT SUSTAINABILITY

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SUSTAINABILITY GOALS: BROOKLINE HIGH SCHOOL EXPANSION

- EUI Target: 25 - 30
- LEED Minimum Certification Level: Silver
- Create a comfortable learning environment filled with natural light
- Design with future flexibility in mind
- Efficient, long lasting, and low maintenance MEP Systems
- Solar Ready

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SUSTAINABILITY METRICS

ENERGY CONSERVATION

- Life Cycle Cost Analysis (LCCA)
- Energy Use Intensity (EUI)
- Zero Greenhouse Gas Emissions
- Net Zero: How much solar is required to bring the Project to Net Zero Site Energy?
- LEED

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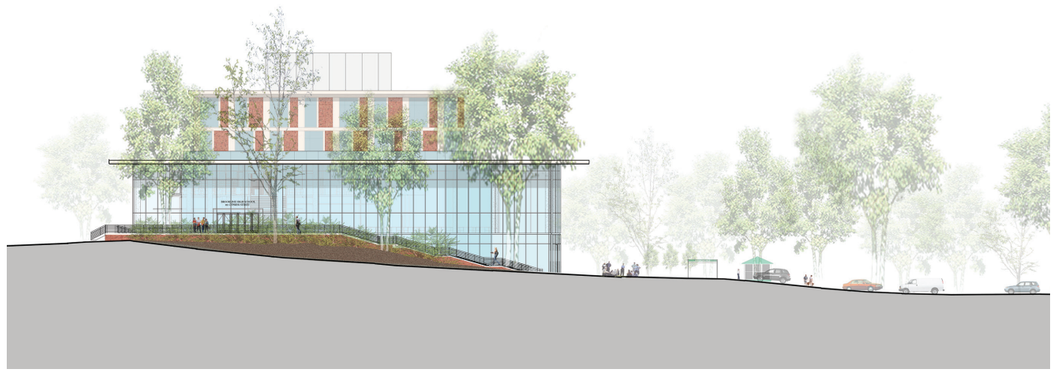
111 CYPRESS BUILDING



- 118,000 GSF academic building consisting of classrooms, library, cafeteria, office, and support spaces

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CYPRESS BUILDING: ENERGY MODEL METHODOLOGIES

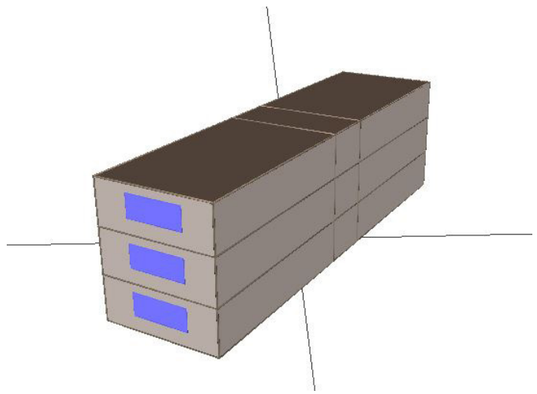
DEFINITIONS

BASELINE CASE: (ASHRAE 90.1-2010)

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

DESIGN CASE: EARLY SD BLOCK MODEL

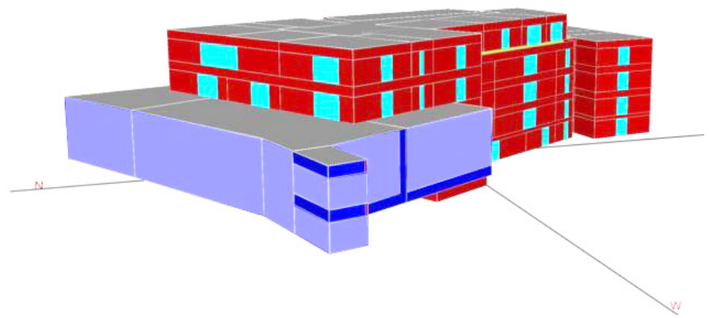
A Block model representing classroom and circulation areas modeled in eQUEST to compare HVAC alternatives.



Block Model

DESIGN CASE: CURRENT SD ENERGY MODEL

The building as designed. The design inputs are based on the Schematic Design drawing and documents, the SD narratives and information provided by the design team. Every effort has been made to use reasonable assumptions for building components and systems where details were not available.



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ASSUMPTIONS: MECHANICAL SYSTEMS

SUMMARY

	BASELINE CASE	DESIGN CASE: EARLY SD BLOCK MODEL	DESIGN CASE: CURRENT SD ENERGY MODEL
		HVAC Options studied:	
	• Packaged VAV with Reheat (DX/HW), with natural draft boilers • Natural Draft Boilers (80% efficiency)	• Option 1: VAV RTU with Gas Boiler • Option 2: Displacement Dehumidification, WC Chiller, High Efficiency Gas Boilers • Option 3: Variable Refrigerant Flow Heat Pumps, All Electric • Option 4: Chilled Beams, WC Chiller, Gas Boiler	• (Option 2 from Block Model) Displacement Dehumidification, WC Chiller, High Efficiency Gas Boilers (95.4% efficiency) • The building classrooms will be heated, ventilated and dehumidified only, providing partial cooling. • Full air conditioning will be provided in Faculty spaces, Library and White Box zone

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ASSUMPTIONS: ENVELOPE

SUMMARY

	BASELINE CASE	DESIGN CASE: EARLY SD BLOCK MODEL	DESIGN CASE: CURRENT SD ENERGY MODEL
WALL	U-VALUE: 0.064 **R-VALUE: 13.0 + 7.5 C.I.**	**R-VALUE: 27**	U-VALUE: 0.036 **R-VALUE: 27.62**
ROOF	U-VALUE: 0.048 **R-VALUE: 20 C.I.**	**R-VALUE: 30**	U-VALUE: 0.024 **R-VALUE: 40 C.I.**
SPANDREL GLASS	U-VALUE: __ R-VALUE: __		U-VALUE: 0.045 **R-VALUE: 22.22**
CURTAIN WALL	U-VALUE: 0.45 **R-VALUE: 2.22** SHGC: 0.4	40% GLAZED U-VALUE: 0.40 **R-VALUE: 2.5**	U-VALUE: 0.39 **R-VALUE: 2.56** SHGC: 0.38
PUNCHED WINDOWS	U-VALUE: 0.55 **R-VALUE: 1.82** SHGC: 0.4		U-VALUE: 0.39 **R-VALUE: 2.56** SHGC: 0.27

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ASSUMPTIONS: LIGHTING

SUMMARY

	BASELINE CASE	DESIGN CASE: EARLY SD BLOCK MODEL	DESIGN CASE: CURRENT SD ENERGY MODEL
LIGHTING POWER DENSITY	• Calculation Method: Building Area Method • Lighting Power Density: 0.99 W/SF	N/A	• Calculation Method: Building Area Method • Lighting Power Density: 0.7 W/SF (20% below ASHRAE 2013)
DAYLIGHT DIMMING CONTROLS	• Included where required by AHSRAE 90.1 2010	N/A	• Perimeter Zones: Stepped dimming to 70% and 35% of full power
EQUIPMENT POWER DENSITY	• Same as Design	N/A	• Kitchen (STEM & Cypress): 5.0 W/SF • Office (STEM & Cypress): 1.5 W/SF • Chem & Bio Labs (STEM): 2.5 W/SF • Cafe (STEM): 2.5 W/SF • Classroom (Cypress): 0.75 W/SF

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ASSUMPTIONS: SCHEDULE & UTILITY RATES

SUMMARY

	BASELINE CASE	DESIGN CASE: EARLY SD BLOCK MODEL	DESIGN CASE: CURRENT SD ENERGY MODEL
PROJECT FLOOR AREA	118,000 SF	SAME AS BASELINE	SAME AS BASELINE
SCHEDULE	EXTENDED SCHEDULE: ACADEMIC USE SCHEDULE + PARTIAL USE OF BUILDING AFTER HOURS, WEEKENDS AND SUMMER	TYPICAL HIGH SCHOOL SCHEDULE WITH HEAVY SUMMER USE	SAME AS BASELINE
UTILITY RATES	ELECTRICITY $0.157 / KWH GAS $9.89 / MBTU *Based on 2017 EIA State Average Rates*	ELECTRICITY $0.16/KWH GAS $1.10/THERM *Based on values provided by Miyakoda Consulting*	SAME AS BASELINE

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CYPRESS BUILDING: CONCEPTUAL “BLOCK” MODEL

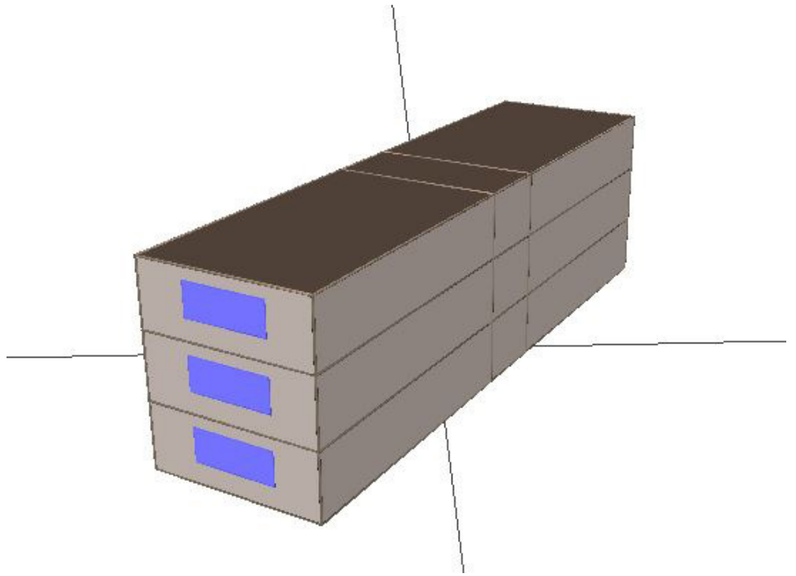
HVAC SYSTEMS

Method

- A Block model representing classroom and circulation areas modeled in eQUEST to compare HVAC alternatives

Basic Assumptions*

- 40% Glazed
- R-30 Roof
- R-27 Walls
- U=0.40 Windows
- Typical High School schedule, with heavy summer use



Block Model

HVAC Options

- Option 1: VAV RTU with Gas Boiler
- Option 2: Displacement Dehumidification, WC Chiller, Gas Boiler
- Option 3: Variable Refrigerant Flow Heat Pumps, All Electric
- Option 4: Chilled Beams, WC Chiller, Gas Boiler

** At the time of block model analysis, building massing had been determined, but fenestration had not been designed.*

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RESULTS: SITE ENERGY USE INTENSITY (EUI)

CONCEPTUAL "BLOCK" MODEL

HVAC OPTIONS	SITE EUI* (kbtu/sf/yr)	ANNUAL COST SAVINGS*
Option A: VAV RTU with Gas Boiler	**39.7**	base
Option B: Displacement Dehumidification, WC Chiller, Gas Boiler	**36.4**	8.3%
Option C: Variable Refrigerant Flow Heat Pumps, All Electric	**35.2**	11.3%
Option D: Chilled Beams, WC Chiller, Gas Boiler	**38.7**	2.5%

**ANNUAL COST SAVINGS WHEN COMPARED TO OPTION A*

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RESULTS: ANNUAL ENERGY COST

CONCEPTUAL "BLOCK" MODEL

HVAC OPTIONS	ENERGY COST ($/SF-YR)	CAPITAL COST ($/SF)	MAINTENANCE COST ($/SF-YR)	EXPECTED OVERALL SERVICE LIFE	TOTAL ANNUAL EQUIV. COST ($/SF-YR)
Option A: VAV RTU with Gas Boiler	$1.58	$52.0	$0.23	20 YEARS	**$5.31**
Option B: Displacement Dehumidification, WC Chiller, Gas Boiler	$1.45	$52.0	$0.20	20 YEARS	**$5.14**
Option C: Variable Refrigerant Flow Heat Pumps, All Electric	$1.66	$42.0	$0.33	15 YEARS	**$5.51**
Option D: Chilled Beams, WC Chiller, Gas Boiler	$1.56	$54.0	$0.28	20 YEARS	**$5.47**

Based on values provided by Miyakoda Consulting:
Electricity $0.16/kWh
Gas $1.10/Therm

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RESULTS: CARBON EMISSIONS

CONCEPTUAL "BLOCK" MODEL

HVAC OPTIONS	CARBON EMISSION / SF (kg CO2e)	PERCENT IMPROVEMENT
Option A: VAV RTU with Gas Boiler	2.86	base
Option B: Displacement Dehumidification, WC Chiller, Gas Boiler	2.62	8.3%
Option C: Variable Refrigerant Flow Heat Pumps, All Electric	2.70	5.5%
Option D: Chilled Beams, WC Chiller, Gas Boiler	2.80	2.1%

Based on eGrid Emission Factors for New England

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SUMMARY OF CONCEPTUAL BLOCK MODEL RESULTS

CONCEPTUAL "BLOCK" MODEL

HVAC OPTIONS	SITE EUI	ENERGY COST					CARBON EMISSIONS	
	SITE EUI (KBTU/SF/YR)	ENERGY COST ($/SF-YR)	CAPITAL COST ($/SF)	MAINTENANCE COST ($/SF-YR)	EXPECTED OVERALL SERVICE LIFE	TOTAL ANNUAL EQUIV. COST ($/SF-YR)	CARBON EMISSION / SF (KG CO2E)	PERCENT IMPROVEMENT
Option A: VAV RTU with Gas Boiler	39.7	$1.58	$52.0	$0.23	20 YEARS	$5.31	2.86	base
Option B: Displacement Dehumidification, WC Chiller, Gas Boiler	36.4	$1.45	$52.0	$0.20	20 YEARS	$5.14	2.62	8.3%
Option C: Variable Refrigerant Flow Heat Pumps, All Electric	35.2	$1.66	$42.0	$0.33	15 YEARS	$5.51	2.70	5.5%
Option D: Chilled Beams, WC Chiller, Gas Boiler	38.7	$1.56	$54.0	$0.28	20 YEARS	$5.47	2.80	2.1%

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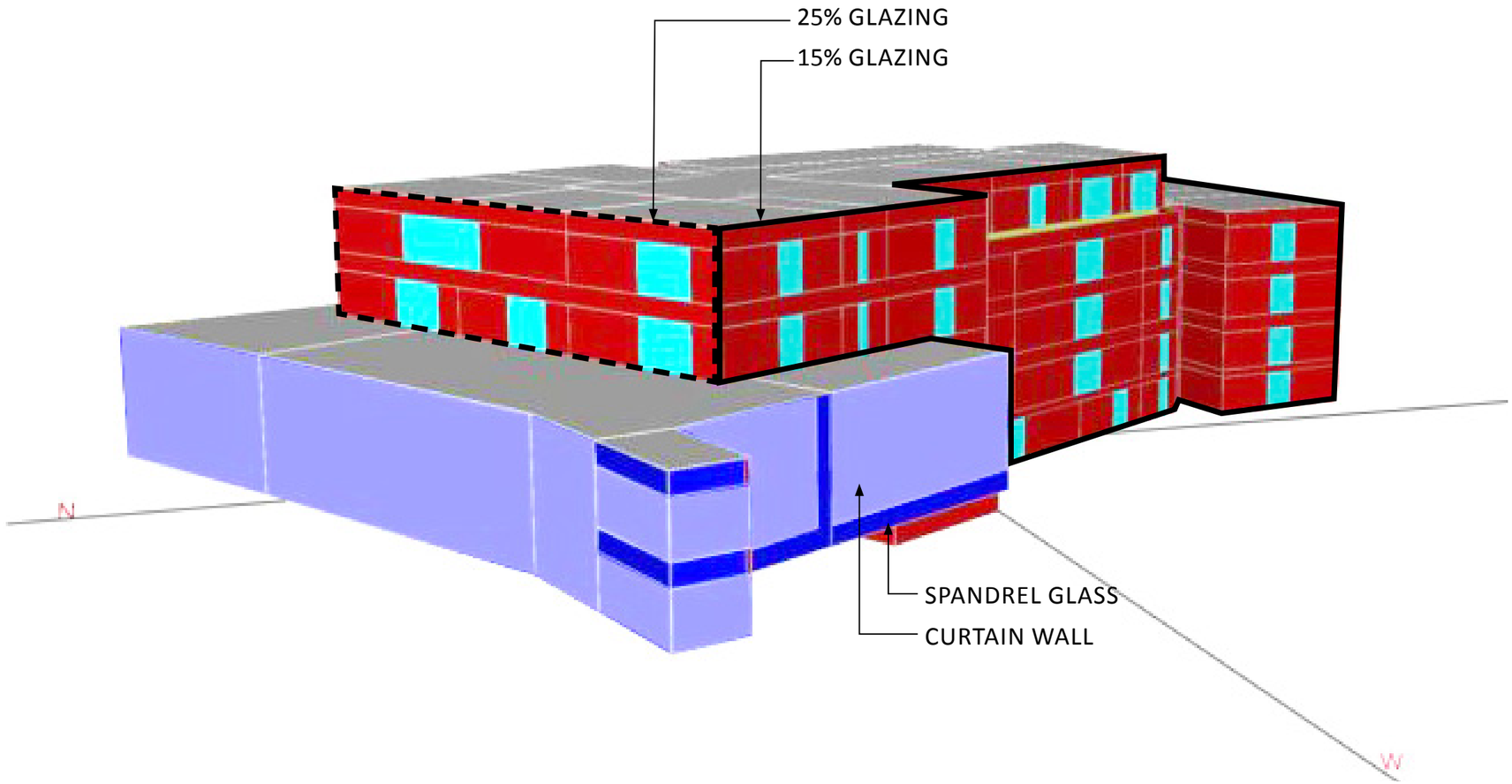
CYPRESS BUILDING: SD ENERGY MODEL

CURRENT DESIGN: EQUEST ENERGY MODEL - 3D VIEW



25% GLAZING

15% GLAZING

BRICK VENEER

PUNCHED WINDOW

CURTAIN WALL

SPANDREL GLASS

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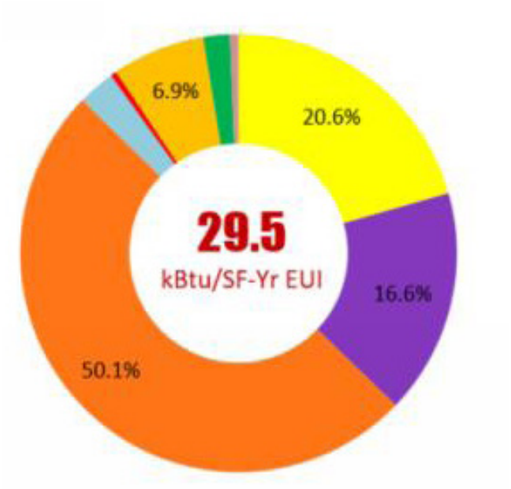
CYPRESS BUILDING SD ENERGY MODEL RESULTS: EUI

ENERGY USE INTENSITY COMPARISON (CURRENT DESIGN) - SCHEDULE

ANTICIPATED EXTENDED HOURS SCHEDULE

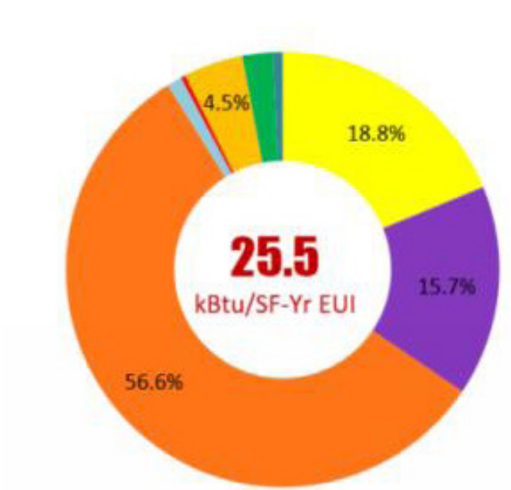
- Monday - Friday 8:00am - 3:00pm
- Evenings, Saturdays, Sundays (Adult Ed, Community events)
- Summer Use



- EUI = 29.5
- Annual Energy Cost = $95,210

ACADEMIC USE ONLY SCHEDULE

- Monday - Friday 8:00am - 3:00pm
- No Summer Use



- EUI = 25.5
- Annual Energy Cost = $74,949

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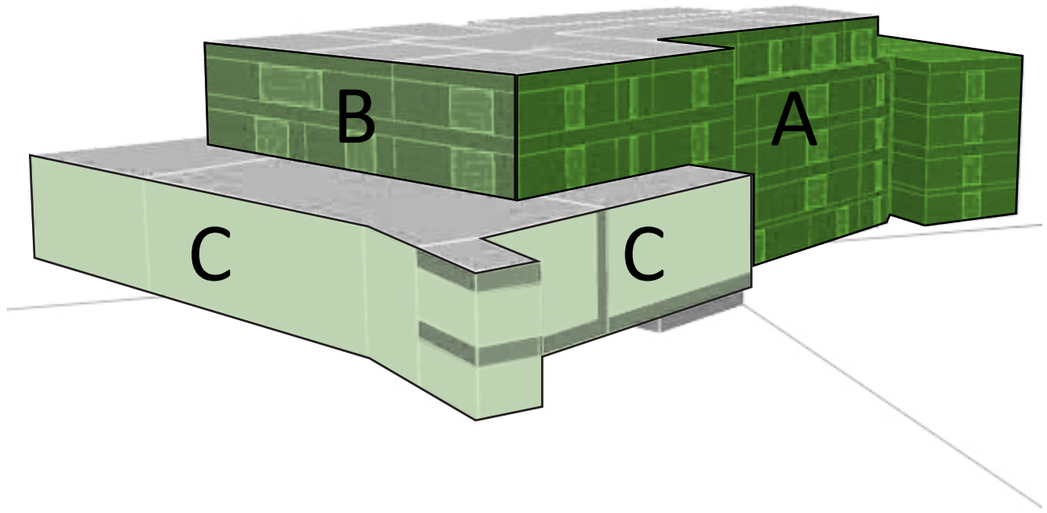
CYPRESS BUILDING SD ENERGY MODEL RESULTS: ENVELOPE OPTIONS

BUILDING ENVELOPE DESIGN OPTIONS

	EUI*
CURRENT DESIGN	**29.5**
• Facades B with 25% WWR**	
• Facades A with 15% WWR	
OPTION 1: Glazing Reduction in Facades A and B	**29.2**
• Facades with 25% WWR reduced to 20% WWR	
• Facades with 15% WWR reduced to 10% WWR	
OPTION 2: Further Glazing Reduction in Facades A & B	**29.0**
• Facades with 25% WWR reduced to 15% WWR	
• Facades with 15% WWR reduced to 5% WWR	
OPTION 3: Increase in Spandrel Glass in Facade C	**29.3**
• A-307 Change 1,000 sf of CW to Spandrel	
• A-305 Change 1,000 sf of CW to Spandrel	
OPTION 4: Glazing Reduction in A & B; Spandrel Increase in C	**29.0**
• Option-1 & Option-3	
OPTION 5: No Windows	**26.5**
• Remove all windows from building (to demonstrate total impact of windows)	
OPTION 6: Current Design with Triple Glazing	**27.7**
• Window assembly U-value reduced from 0.39 to 0.30	

** Based on Anticipated Extended Hours Schedule*

***WWR: Window-to-Wall Ratio*



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CYPRESS BUILDING SD ENERGY MODEL RESULTS: LEED

LEED

LEED GOAL (MINIMUM)

SILVER

CERTIFICATION REQUIREMENTS

CERTIFIED	40-49 POINTS
SILVER	50-59 POINTS
GOLD	60-79 POINTS
PLATINUM	80+ POINTS

LEED SCORECARD SUMMARY (AS OF MARCH 30, 2018)*

YES	49
MAYBE	38
NO	23

EAc2 OPTIMIZE ENERGY PERFORMANCE

14 Points (Town Goal: 13 pts)

** See Appendix for detailed LEED Scorecard*

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CYPRESS BUILDING: ENERGY CONSERVATION MEASURES (ECM)

SUMMARY

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

- Improved envelope assemblies and fenestration
- Reduced interior lighting through the use of high efficiency LED fixtures
- High efficiency VAV with energy recovery better than ASHARE 90.1 requirements
- The design includes partial cooling for all classroom spaces. This results in a lower overall energy use for the project
- Supply air temperature reset
- Perimeter finned tube radiators (FTR's) with hot water heating
- Perimeter FTR's meet space loads during unoccupied periods eliminating the need for roof top VAV units to cycle on at night and unoccupied periods
- High efficiency condensing boilers and optimized hot water loop parameters
- High efficiency air-cooled chiller and optimized chilled water loop parameters

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ROOF MOUNTED PHOTOVOLTAIC PANELS

ROOF AREA:	8,963 SF
ANNUAL KWH PRODUCTION:	150,480 KWH
VALUE OF ELECTRICITY GENERATED ANNUALLY:	$23,625
% OF TOTAL BUILDING ENERGY USE (ELECT & GAS)	14.7%

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CYPRESS BUILDING: NET ZERO FEASIBILITY

ADDITIONAL PV PANELS NEEDED TO ACHIEVE NET ZERO

AREA NEEDED FOR PV INSTALLATION:	51,895 SF
ANNUAL KWH PRODUCTION:	870,804 KWH
ESTIMATED INSTALLATION COST:	$2,706,136*

** Does not include cost of panels mounted to Cypress roof which are not included in the SD budget.*

State of Massachusetts Net Zero Definition

"A net zero building is one that is optimally efficient and, over the course of a year, generates energy onsite, using clean renewable resources, in a quantity equal to or greater than the total amount of energy consumed on site"

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STEM WING

- 70,000 sf addition to the existing Greenough Street Main Building, consisting of a new culinary arts kitchen/café, biology and chemistry classlabs, maker spaces, and collaborative spaces.

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STEM WING: CONCEPTUAL BLOCK MODEL - CHILLER OPTIONS

COMPARISON OF WATER-COOLED (WC) & AIR-COOLED (AC) CHILLER

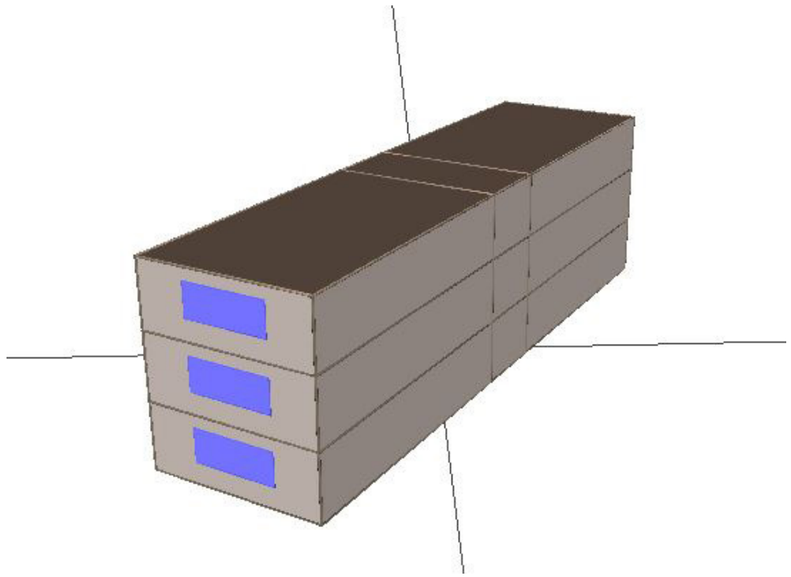
Chiller Design Basic Assumptions

- 400 ton capacity, assumes 600 full load hours per year

Chiller Options

- Option 1: Air Cooled Chiller
  Screw compressor chiller NPLV =13.7

- Option 2: Water Cooled Chiller
  Multi-stack modular 0.6kw/ton, 60 ft head condenser water pumping, cooling tower fans 0.05 hp/ton



Note: As an addition to the Main High School Building, STEM Wing HVAC systems will be supported by the current boiler plant in the Unified Arts Building. The existing 80% efficiency boilers will be replaced with 85% efficiency boilers. Since the mechanical plant will not be completely replaced, chiller selection will have the greatest impact on STEM Wing energy efficiency.

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STEM WING CONCEPTUAL BOX MODEL RESULTS: CHILLER OPTIONS

COMPARISON OF WATER-COOLED (WC) & AIR-COOLED (AC) CHILLER: RESULTS

CHILLER TYPE	ELECTRICAL CONSUMPTION / YEAR (kWh)	COST / YEAR ($)	COST SAVINGS ($)	SITE SAVINGS (kbtu/sf/yr)
OPTION 1: Air Cooled	210,000	$31,500	base	base
OPTION 2: Water Cooled	161,000	$24,200	$7,300	2.4

Based on values provided by Miyakoda Consulting:
Electricity $0.16/kWh

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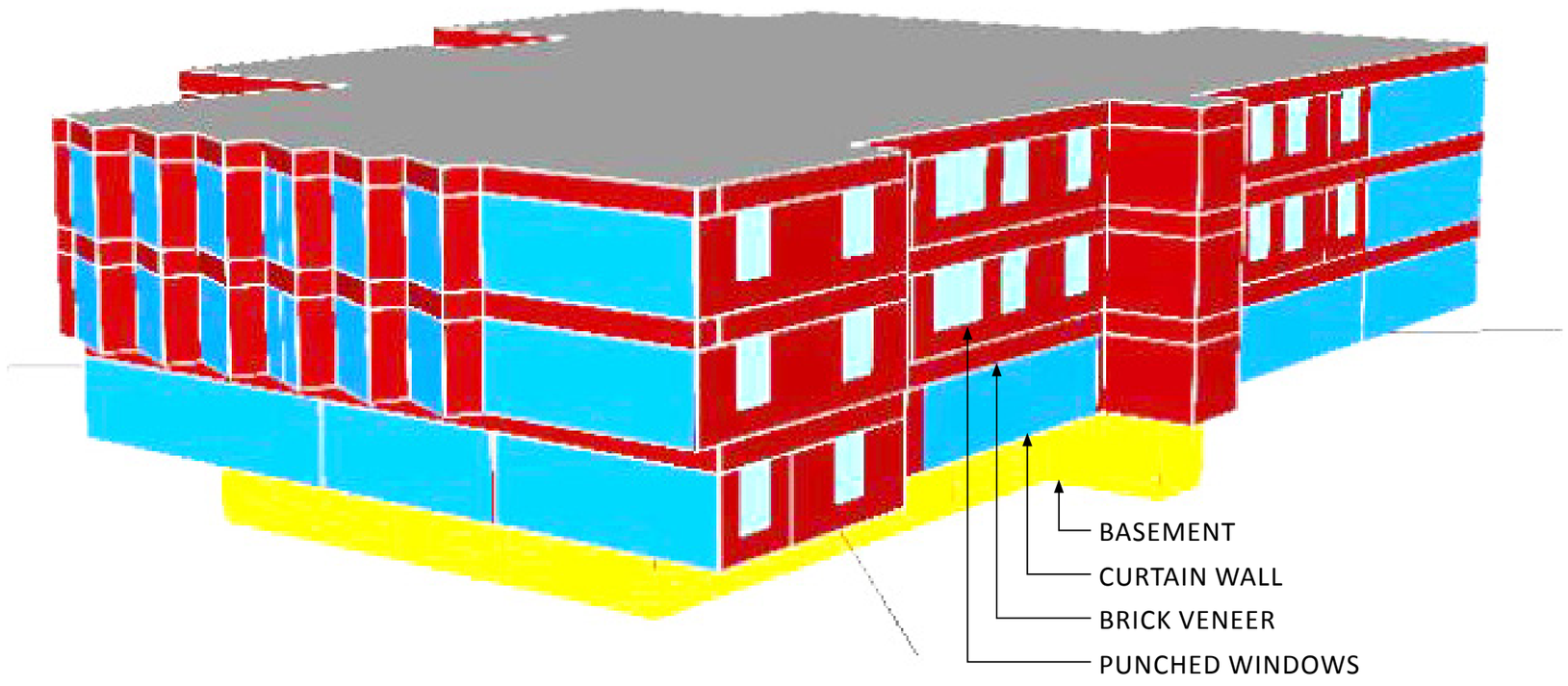
STEM WING: SD ENERGY MODEL

CURRENT DESIGN: EQUEST ENERGY MODEL - 3D VIEW



BRICK VENEER

PUNCHED WINDOW

CURTAIN WALL

BASEMENT

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STEM WING SD ENERGY MODEL INPUTS: SCHEDULE

ANTICIPATED EXTENDED HOURS SCHEDULE

ACADEMIC SCHOOL YEAR

MONDAY - FRIDAY	SATURDAY	SUNDAY
LEVEL 1 8:00AM - 10:00PM	LEVEL 1 8:00AM - 3:00PM	LEVEL 1 *CLOSED*
REST OF BUILDING* 8:00AM - 3:00PM	REST OF BUILDING *CLOSED*	REST OF BUILDING *CLOSED*

**REST OF BUILDING: BASEMENT, LEVEL 2, LEVEL 3*

SUMMER

MONDAY - FRIDAY	SATURDAY	SUNDAY
LEVEL 1** 8:00AM - 3PM	LEVEL 1** 8:00AM - 3:00PM	LEVEL 1** *CLOSED*
REST OF BUILDING *CLOSED*	REST OF BUILDING *CLOSED*	REST OF BUILDING *CLOSED*

***EXCEPT KITCHEN, WHICH IS CLOSED DURING THE SUMMER*

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STEM WING: SD ENERGY MODEL INPUTS: ENVELOPE & LIGHTING

BUILDING ENVELOPE & LIGHTING :
SAME AS CYPRESS BUILDING

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STEM WING: SD ENERGY MODEL INPUTS: MECHANICAL SYSTEMS

BASELINE DESIGN

- ASHRAE 90.1 2010
- Packaged VAV with Reheat (DX/Purchased HTHW)
- Natural draft boilers (80% efficiency)

CURRENT DESIGN

- The building classrooms will be heated, ventilated and dehumidified only, providing partial cooling. Full air conditioning will be provided in Faculty spaces through the building air system.
- Indoor design criteria will be 70°F in winter and 80°F/50%RH in summer for the dehumidified areas and 75°F/50%RH in summer for the fully air conditioned areas.
- Building heating will be provided from the existing campus hot water heating plant. The existing building heat exchanger and pumping system will be upgraded to handle the added heating loads associated with the STEM addition. Boilers will be replaced with 85% efficiency boilers.
- Building cooling, ventilation and dehumidification will be provided by curb mounted rooftop units.

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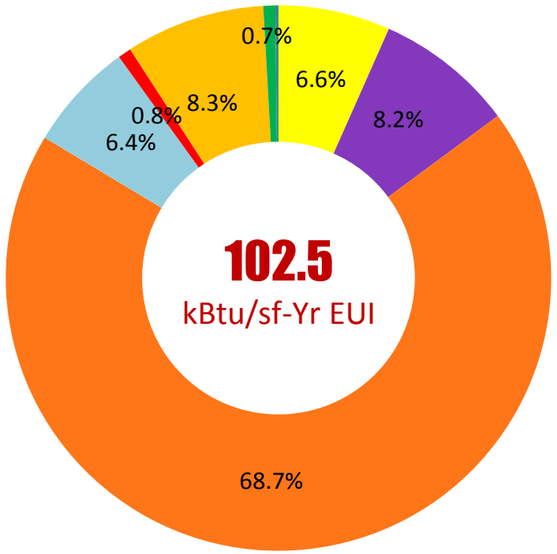
STEM WING: SD ENERGY MODEL RESULTS

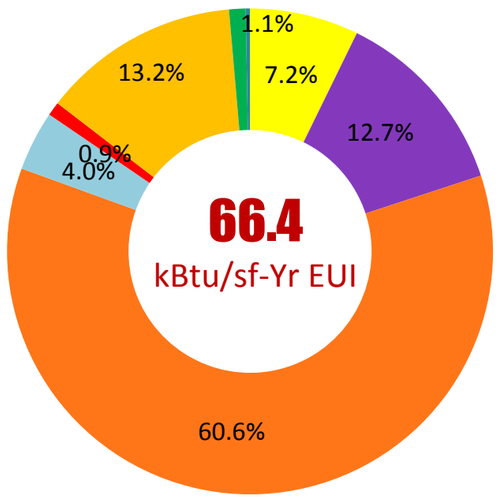
ENERGY USE INTENSITY COMPARISON - BASELINE VS CURRENT DESIGN

BASELINE DESIGN



- EUI = 102.5
- Annual Energy Cost = $149,630
- Greenhouse Gas (GHG) Emissions = 388,960 kg CO2e

CURRENT DESIGN



- EUI = 66.4*
- Annual Energy Cost = $109,925 (26.5% energy cost savings
- Greenhouse Gas (GHG) Emissions = 282,185 kg CO2e (27.4% reduction)

**Town EUI target of 25-30 cannot be achieved due to code required air exchange rates for science laboratories and HVAC systems fed from the existing high temperature boilers in UAB*

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STEM WING SD ENERGY MODEL RESULTS: LEED

RESULTS: LEED

The Current Design Case is expected to show:

- **ANNUAL ENERGY-USE SAVINGS: 27.8%**
  as compared to an ASHRAE 90.1 2010 compliant Baseline building.

- **TOTAL ENERGY-COST SAVINGS: 24.2%**
  as compared to an ASHRAE 90.1 2010 compliant Baseline building.

- **EAc2 OPTIMIZE ENERGY PERFORMANCE**
  11 points (26.5% energy cost savings)*

  **Energy performance is limited by existing HVAC system in the Unified Arts Building. Higher efficiency, low temperature boilers cannot be specified without replacing all distribution piping through the Greenough Building with larger diameter pipes.*

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STEM WING: ENERGY CONSERVATION MEASURES (ECM)

SUMMARY

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

- Improved envelope assemblies and fenestration
- Reduced interior lighting through the use of high efficiency LED fixtures
- High efficiency 100% outside air VAV energy recovery units for ventilation
- 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) with hot water heating.
- Perimeter FTR's meet space loads during unoccupied periods eliminating the need for roof top VAV units to cycle on at night and unoccupied periods.
- Un-occupied ACH in lab spaces lower than ASHARE 90.1 2010 requirements
- Higher efficiency boilers and optimized hot water loop parameters
- High efficiency air-cooled chiller and optimized chilled water loop parameters

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ROOF MOUNTED PHOTOVOLTAIC PANELS

ROOF AREA:	7,252 SF
ANNUAL KWH PRODUCTION:	127,273 KWH
VALUE OF ELECTRICITY GENERATED ANNUALLY:	$19,982
% OF TOTAL STEM WING ENERGY USE (ELECT)	24.5%
% OF TOTAL GREENOUGH ST BUILDING (ELECT)	9.4%

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ADDITIONAL PV PANELS NEEDED TO ACHIEVE NET ZERO

AREA NEEDED FOR PV INSTALLATION:	73,370 SF
ANNUAL KWH PRODUCTION:	1,231,152 KWH
ESTIMATED INSTALLATION COST:	$3,825,968*

** Does not include cost of panels mounted to Cypress roof which are not included in the SD budget.*

State of Massachusetts Net Zero Definition

"A net zero building is one that is optimally efficient and, over the course of a year, generates energy onsite, using clean renewable resources, in a quantity equal to or greater than the total amount of energy consumed on site"

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BHS UTILITY COST COMPARISON

SUMMARY

	CURRENT			ANTICIPATED		
	GROSS FLOOR AREA	**TOTAL UTILITY COSTS**	**TOTAL UTILITY COSTS / SF**	**GROSS FLOOR AREA**	**TOTAL UTILITY COSTS**	**TOTAL UTILITY COSTS / SF**
MAIN BUILDING	*337,930	$321,837	$0.95	**367,541	$393,535	$1.07
TAPPAN GYM + POOL	114,433	$329,630	$2.88	***116,574	$335,797	$2.88
UNIFIED ARTS BUILDING	56,176	$104,275	$1.86	56,176	$104,275	$1.86
CYPRESS BUILDING	N/A	N/A	N/A	118,000	$94,567	$0.80
TOTAL	**508,539**	**$755,742**	**$1.49**	**658,291**	**$928,174**	**$1.41**

Notes:
** Main Building + Roberts Wing*
*** Main Building + STEM Wing: Energy cost for remaining Main Building calculated based on current unit cost*
**** Tappan Gym + Pool + New Entry Addition: Energy cost for new Entry Addition calculated based on current unit cost*

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