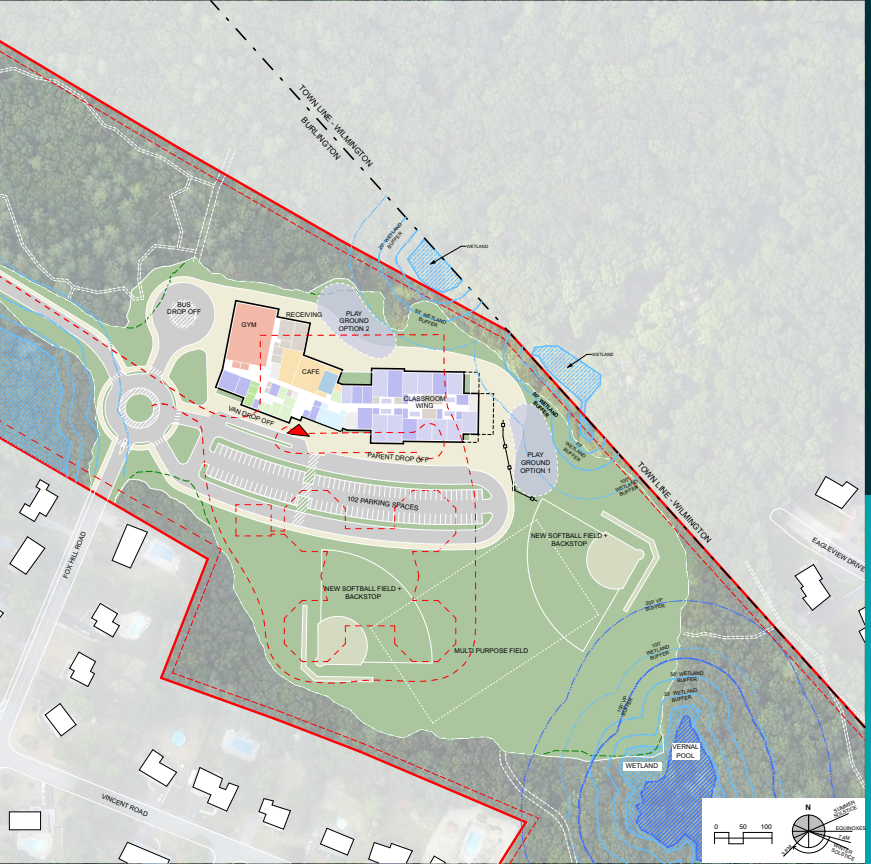


November 15, 2023

Fox Hill Elementary School

EUI and LCCA Results (Feasibility Phase)

Thornton Tomasetti

AGENDA

1. Fox Hill’s Energy Goals
2. Feasibility Energy Use Intensity (EUI) Results
3. Feasibility LCCA Results
4. Takeaways & Discussion

Sustainability Definitions

NZE - Net zero energy. Energy used is equal to that produced on site

Triple Net Zero - Net zero energy, water and waste

GSHP - Ground source heat pump with geothermal wells. An HVAC plant producing heating and cooling from energy in the ground, typically using a 4 pipe water system to distribute the heating and cooling.

ASHP – Air source heat pump. An HVAC plant producing heating and cooling from energy in the air, typically using a 4 pipe water system to distribute the heating and cooling.

VRF - Variable Refrigerant Flow. An HVAC plant on the roof that produces heating and cooling from energy in the air and distributes the heating and cooling with a refrigerant piping system

LEED - Leadership in Energy and Environmental Design. A sustainability rating system

CHPS - Collaborative for High Performing Schools. A sustainability rating system

EUI – Energy Use Intensity (kBTU/sf/year)

LCCA - Lifecycle Cost Analysis

TEDI - Thermal Energy Demand Intensity - Annual heating energy demand for space conditioning and conditioning of ventilation air

1 Energy Goals

Fox Hill's Energy Goals

1. **Net Zero Energy**
2. **MA Energy Code**
    - Stretch code TEDI targets: ≈**2.3** kBtu/ft^2/yr heating TEDI, ≈**18** Btu/ft^2/yr cooling TEDI
    - Minimum envelope performance requirements
3. **Mass Save Incentives**
    - Energy use intensity (EUI): **25** kBtu/ft^2/yr
4. **MSBA Green Schools Program**
    - Meet MA Energy Code (Stretch and Specialized code requirements (225 CMR 23))
    - Specialized code: all-electric

Feasibility Phase Analysis

1. **Net Zero Energy**
2. **MA Energy Code**
   - Stretch code TEDI targets: ≈**2.3** kBtu/ft²/yr heating TEDI, ≈**18** Btu/ft²/yr cooling TEDI
   - Minimum envelope performance requirements
3. **Mass Save Incentives**
   - Energy use intensity (EUI): **25** kBtu/ft²/yr
4. **MSBA Green Schools Program**
   - Meet MA Energy Code (Stretch and Specialized code requirements (225 CMR 23))
   - Specialized code: all-electric

+ LCCA

2 Energy Use Intensity

Energy Model Inputs

Geometry:

- 2-story massing

Envelope Assumptions:

- **Roof:** R-31*
- **Wall:** R-18* (effective performance, including clear field and linear thermal bridges)
- **Window:** U-0.25* (triple glazing)
- **Window to Wall Ratio:** 22%
- **Infiltration:** 0.25 cfm/ft^2 @ 75 Pa

**2023 Stretch Code prescriptive requirements*

Internal Loads:

- **Lighting Power Density:** 0.55 W/ft^2 (building area method)
- **Plug loads:** Classroom: 1.00 W/ft^2, Office: 0.75 W/ft^2 (ASHRAE 90.1-2016 User's Manual)

Energy Model Inputs

Setpoints:

- Occupied cooling set point: 76°F / 50%RH (Relative Humidity). No unoccupied cooling.
- Occupied heating set point: 70°F with no humidification. Unoccupied heating set point: 55°F.

Ventilation control:

- Occupied spaces: Demand control ventilation
- Kitchen: 4,500 makeup air with 30%-100% variable speed control

Occupancy Schedule

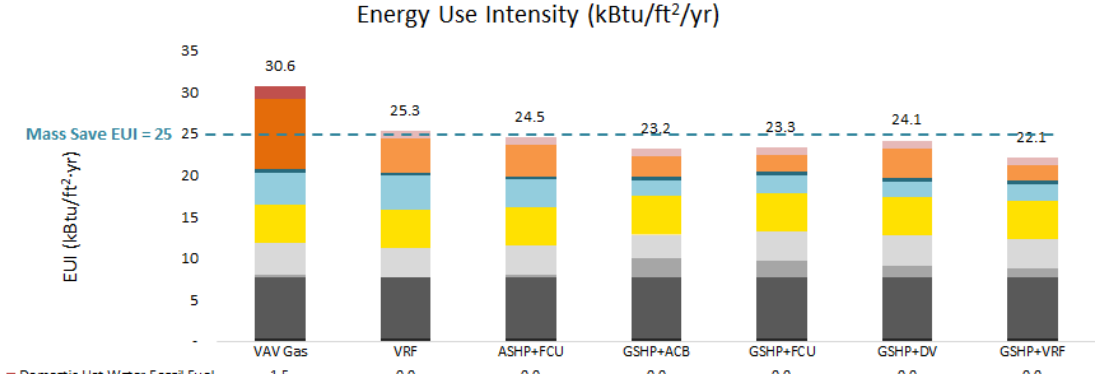
Proposed Usage Schedule

	"SCHOOL USE"						"ANTICIPATED USE" (Not School Use)																				
	SCHOOL YEAR			SUMMER BREAK			SCHOOL YEAR Last full week in August to End of June									SUMMER BREAK July to August									VACATION WEEKS								
Space Description	Monday - Friday 44 Weeks			Monday - Friday 8 Weeks			Monday - Friday 45 Weeks			Saturday 32 Weeks			Sunday			Monday - Friday			Saturday			Sunday			Winter Vacation			February Vacation			April Vacation		
FIRST FLOOR																																	
Administration	6:30 AM	to	6:00 PM	8:00 AM	to	3:00 PM	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-		to			to			to	
Gymnasium	6:30 AM	to	6:00 PM	8:00 AM	to	9:00 AM	6:00 PM	to	10:00 PM	7:00 AM	to	5:00 PM	7:00 AM	to	5:00 PM	-	to	-	-	to	-	-	to	-		to			to			to	
1st Floor Toilets Serving Gym	6:30 AM	to	6:00 PM	8:00 AM	to	3:00 PM	6:00 PM	to	10:00 PM	7:00 AM	to	5:00 PM	7:00 AM	to	5:00 PM	-	to	-	-	to	-	-	to	-		to			to			to	
1st Floor Corridors	6:30 AM	to	6:00 PM	8:00 AM	to	3:00 PM	6:00 PM	to	10:00 PM	7:00 AM	to	5:00 PM	7:00 AM	to	5:00 PM	-	to	-	-	to	-	-	to	-		to			to			to	
Cafeteria	6:30 AM	to	6:00 PM	8:00 AM	to	1:00 PM	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-		to			to			to	
Kitchen	6:30 AM	to	2:00 PM	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-		to			to			to	
Classrooms	6:30 AM	to	6:00 PM	8:00 AM	to	3:00 PM	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-		to			to			to	
SECOND FLOOR																																	
Classrooms	6:30 AM	to	6:00 PM	8:00 AM	to	3:00 PM	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-		to			to			to	
Library	6:30 AM	to	6:00 PM	8:00 AM	to	3:00 PM	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-	-	to	-		to			to			to	

Mechanical Options Studied

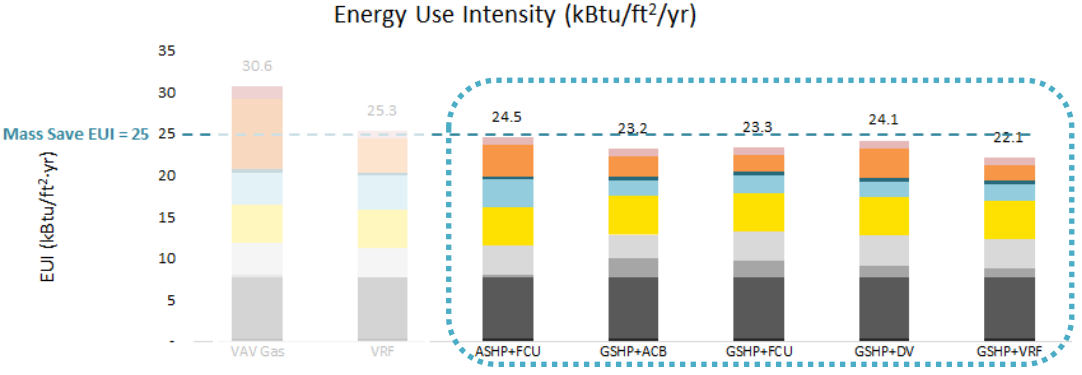
	Central Plant	Air Distribution Side
VAV Gas	Gas boilers, air-cooled chiller	VAV with reheat
VRF	Air source VRF outdoor condensing units	ERV with air source VRF fan coil units
ASHP+FCU	Air source heat pump with electric boiler backup	ERV with fan coil units
GSHP+ACB	Ground source heat pump	ERV with chilled beams
GSHP+FCU	Ground source heat pump	ERV with fan coil units
GSHP+DV	Ground source heat pump	Displacement ventilation
GSHP+VRF	Ground source heat pump	ERV with water source VRF indoor units

Results: Energy Use Intensity



	VAV Gas	VRF	ASHP+FCU	GSHP+ACB	GSHP+FCU	GSHP+DV	GSHP+VRF
Domestic Hot Water Fossil Fuel	1.5	0.0	0.0	0.0	0.0	0.0	0.0
Domestic Hot Water Electricity	0.0	0.9	0.9	0.9	0.9	0.9	0.9
Space Heating Fossil Fuel	8.4	0.0	0.0	0.0	0.0	0.0	0.0
Space Heating Electricity	0.0	4.1	3.8	2.4	2.0	3.6	1.9
Refrigeration	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Space Cooling Electricity	3.9	4.1	3.3	2.0	2.1	1.8	2.0
Internal Lighting	4.6	4.6	4.6	4.6	4.6	4.6	4.6
Exterior Lighting	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Vent Fans	3.8	3.5	3.5	2.8	3.5	3.7	3.5
Pumps	0.3	0.0	0.3	2.3	2.1	1.3	1.1
Plug Loads	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Elevators	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total Energy	30.6	25.3	24.5	23.2	23.3	24.1	22.1
Total Energy Cost	$115,599	$124,483	$120,942	$114,103	$114,788	$118,758	$108,790

Results: Energy Use Intensity



All ASHP and GSHP options meet the 25 EUI target*

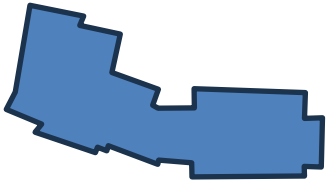
**The EUI estimates reflect an early design modeling assumptions. The EUI may be slightly higher or lower as the project evolves.*

2-story vs. 3-story EUI Assessment

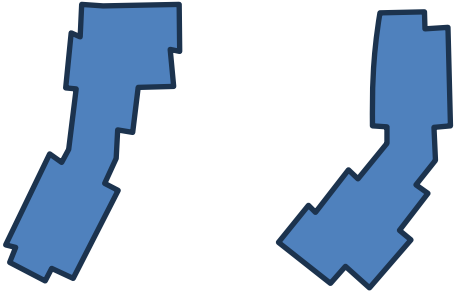
- 2-story vs. 3-story has no significant difference in total EUI (less than 2% change), based on change in envelope area, engineering estimate and previous project experience.

Alternative Orientation EUI Assessment

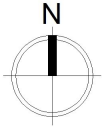
1-2% higher EUI*



North-south orientation
(East-west axis)



East-west orientation
(North-south axis)



*results based on East-west axis model rotated to align along north-south axis

3 Lifecycle Cost Analysis

LCCA Assumptions

- Study period: 50 years
- Escalation rate: 5.5%
- Discount rate: 3.8%
- GSHP well life of 50 years

- Mass Save Incentives:

K-12 Schools	Site EUI Range	Incentives				
		Payable at end of Construction		Payable at end of 1 yr. post occupancy		
		Construction Incentive $/sf	Heat Pump Adder*	Post Occ. Inc. $/sf	Adder for getting under ZNE EUI target	Certification Incentive
Tier 2 (high schools only)	26-29	$1.50	Air Source Heat Pumps: $800/ton	$ 1.50	Not applicable	$3,000
Tier 1 - Net Zero Level (all Schools)	25 or less	$2.00	Variable Refrigerant Flow (VRF): $1200/ton Ground Source Heat Pumps: $4500/ton		$0.05/ EUI point reduction/sf	

LCCA Assumptions

Replacement Costs:

- VRF Replacement 1: 50% of capital cost at Year 15
- VRF Replacement 2: 80% of capital cost at Year 30
- VRF Replacement 3: 50% of capital cost at Year 45
- ASHP Replacement 1: 30% of capital cost at Year 15
- ASHP Replacement 2: 80% of capital cost at Year 30
- ASHP Replacement 3: 30% of capital cost at Year 45
- GSHP Replacement 1: 30% of capital cost at Year 20
- GSHP Replacement 2: 80% of capital cost at Year 40

LCCA Summary

System Type	EUI (kBtu/ft^2/yr)	First Cost Before Incentives ($)	- MassSave Construction Incentives[1] ($)	- MassSave Occupancy Incentives[2] ($)	- IRA Tax Credits[3] ($)	+ Annual Operating Cost ($)	+ Replacement Cost *Net Present Cost* ($)	= 50 yr Life Cycle Cost *Net Present Cost* ($)	= Relative LCC compared to VAV Gas *Net Present Cost*
VAV Gas	30.6	$10,732,506	$0	$0	$0	$115,599	$24,774,243	$44,026,868	$0
VRF	25.3	$9,241,193	$486,428	$130,821	$0	$124,483	$27,529,186	$45,328,035	$1,301,168
ASHP+FCU	24.5	$10,451,068	$382,428	$130,821	$0	$120,942	$24,124,589	$42,976,328	-$1,050,540
GSHP+ACB	23.2	$13,630,294	$1,344,428	$130,821	$4,089,088	$114,103	$22,452,857	$38,928,671	-$5,098,197
GSHP+FCU	23.3	$13,376,069	$1,344,428	$130,821	$4,012,821	$114,788	$21,957,806	$38,306,150	-$5,720,718
GSHP+DV	24.1	$13,244,231	$1,344,428	$130,821	$3,973,269	$118,758	$21,701,079	$38,249,742	-$5,777,126
GSHP+VRF	22.1	$13,448,319	$1,344,428	$130,821	$4,034,496	$108,790	$22,098,498	$38,055,340	-$5,971,528

1. All options below EUI 25.4 kBtu/ft^2/yr: Pathway 1 ($2/ft^2 + HP adder)
2. $1.25/ft^2 for post occupancy if measured EUI meets target
3. The 30% Inflation Reduction Act (IRA) federal tax credit for GSHP is an approximation. Burlington will need to work with a tax attorney to confirm and secure the federal tax credits
4. Incentives and EUI are based on feasibility 2-story configuration *conditioned floor area* of 87,000 ft^2
5. The system will be maintained by the same in-house maintenance crew that the school department already pays salaries for. Therefore, maintenance costs have not been added.

LCCA Summary

System Type	EUI (kBtu/ft^2/yr)	+ Replacement Cost *Net Present Cost* ($)	= 50 yr Life Cycle Cost *Net Present Cost* ($)	= Relative LCC compared to VAV Gas *Net Present Cost*
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All ASHP and GSHP options meet the 25 EUI target

4 Takeaways

Takeaways

1. All ASHP and GSHP options meet the 25 EUI target*

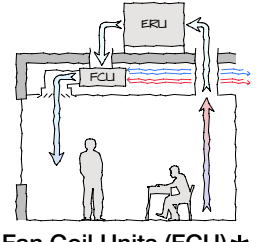
- ASHP+FCU at ≈$1 million net present cost lower than gas baseline (50 yr)
- GSHP options at ≈$5-6 million net present cost lower than gas baseline (50 yr)

**The EUI estimates reflect an early design modeling assumptions. The EUI may be slightly higher or lower as the project evolves.*

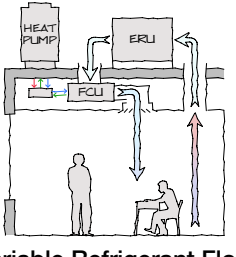
2. 2-story vs. 3-story has no significant difference in total EUI (less than 2% change)

Decisions to be made

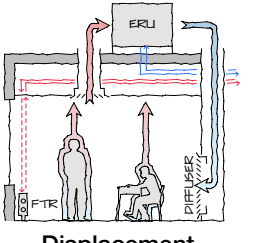
1. All Electric – December 2023
2. GSHP vs ASHP vs VRF – December 2023 - January 2024
3. Distribution System – February 2024
4. Further study for Rainwater Harvesting in Schematic Design



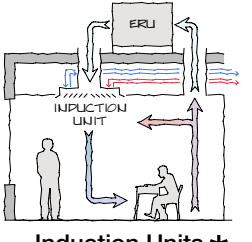
Fan Coil Units (FCU)★



Variable Refrigerant Flow (VRF)



Displacement Ventilation



Induction Units ★ (Chilled Beam)

THANK YOU