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January 4, 2024

Mr. Jerry Song
Senior Energy Engineer
National Grid
40 Sylvan Road
Waltham, MA

RE: Scoping Study for Masconomet Regional High School, Administration Building, and Wastewater Treatment Plant

Dear Jerry,

B2Q is pleased to provide this report summarizing our findings from this scoping study to evaluate potential energy conservation measures (ECMs) and electrification options for the Masconomet Regional High School, as well as the school's Administration Building and Wastewater Treatment Plant, located in Boxford, MA.

INTRODUCTION

B2Q was engaged by National Grid to complete scoping studies at Masconomet Regional School District (the District) to evaluate the potential for electrifying the building's heating systems, as well as to identify other potential energy conversation opportunities. This report focuses on the high school portion of the building, as well as two satellite buildings, the administration building and the wastewater treatment plant. There is a similar, separate report for the middle school portion of the building, including the "link" section with shared spaces between the middle and high schools.

We understand the District is interested in reducing energy costs and upgrading aging systems to improve efficiency and maintainability, while also being interested in exploring options for phasing out the building's use of fossil fuels. As such, this study is intended to provide a list of potential energy savings opportunities and a high-level screening review of various ECMs and heat pump technologies, to give a high-level understanding of the energy savings and CO_2 emissions reductions potential, as well the likely budget impacts.

EXECUTIVE SUMMARY

ELECTRIFICATION SCREENING

Table 1: Electrification Screening Executive Summary Table.

Proposed Electrification Option		Estimated Heat Pump Heating Capacity	Estimated Heat Pump Cooling Capacity	Estimated Annual Electric Savings	Estimated Annual Fossil Fuel Savings	Estimated Annual Energy Cost Savings	Electrification Opinion of Probable Cost	End of Life Equipment Replacement Incremental Cost Budget[1]	Total Estimated Project Cost	Estimated Potential Utility Incentive	Estimated Net Cost
		tons	*tons*	*kWh*	*therms*	*$*	*$*	*$*		*$*	*$*
Option 1A:	VRF Heat Pumps, High School	387	338	-866,820	96,073	-$20,876	$4,463,450	$2,650,583	$7,114,033		
Option 1A:	VRF Heat Pumps, Administration	18	15	47,517	169	$7,993	$280,900	N/A	$280,900	$52,500	$228,400
Option 1B:	RTU Air-to-Air Heat Pump, High School	59	52	-32,561	5,959	$2,177	$558,338	$278,324	$836,662		
Option 1B:	RTU Air-to-Air Heat Pump, WWTP	51	45	-147,062	18,002	-$1,396	$763,888	N/A	$763,888	$112,500	$651,388
Option 2:	Central Air-to-Water Heat Pump, High School	387	338	-930,772	97,481	-$29,573	$3,932,225	$4,285,837	$8,218,062		
Option 1A + 1B, HS:	**Air-to-Air VRF + RTU Heat Pump Total**	**446**	**390**	**-899,381**	**102,032**	**-$18,699**	**$5,021,788**	**$2,928,907**	**$7,950,695**	**$2,295,099**	**$5,655,596**
Option 1B + 2, HS:	**RTU Heat Pump + Central Air-to-Water Heat Pump Total**	**446**	**390**	**-963,333**	**103,440**	**-$27,396**	**$4,490,563**	**$4,564,161**	**$9,054,723**	**$2,482,123**	**$6,572,600**
Heat Pump Water Heater, High School		--	--	-26,439	3,805	$465	$63,100	N/A	$63,100	$2,200	$60,900
Percent of Baseline Usage - Option 1A				*-66%*	*76%*						
Percent of Baseline Usage - Option 1B				*-14%*	*19%*						
Percent of Baseline Usage - Option 2				*-75%*	*77%*						
Percent of Baseline Usage - Heat Pump Water Heater				*-2%*	*3%*						

[1] End of life equipment replacement incremental costs have been taken directly from "Appendix A: HVAC Capital Planning Details" provided by Masco. B2Q understands that Masco obtained quotes for end of life equipment replacements directly from vendors. B2Q has not reviewed nor revised these budget estimates, but rather has included them in the executive summary table in an effort to demostrate an estimate of the total project cost for each electrification option. B2Q only included items from the budget which need to be replaced per Masco, but are not covered in B2Q's opinion of probable cost for the electrification portion of the project.

Table 2: Electrification Screening Summary of CO_2 Emissions Savings.

Option	Estimated Annual CO_2 Emissions Savings		Projected Annual CO_2 Emissions Savings w/100% Carbon Free Electricity Grid	
	lbs	*%*	*lbs*	*%*
VRF Heat Pumps, High School	768,655	39%	1,124,051	76%
VRF Heat Pumps, Administration	21,459	1%	1,977	0%
RTU Air-to-Air Heat Pump, High School	56,372	3%	69,723	5%
RTU Air-to-Air Heat Pump, WWTP	150,328	8%	210,623	14%
Central Air-to-Water Heat Pump, High School	758,912	38%	1,140,528	77%
Heat Pump Water Heater, High School	33,677	2%	44,518	3%

ECM SCREENING

Table 3: ECM Screening Executive Summary Table.

	ECM Description	Electricity Savings	Natural Gas Savings	Energy Cost Savings	Typical Payback			Extrapolated Project Cost Range		
-	-	kWh	therms	$	yr		yr	$		$
1	LED Lighting Upgrades & Lighting Controls	120,921	0	$19,799	3	-	6	$59,396	-	$118,793
2	Pneumatic to DDC Upgrades, New BAS, & Re-Commissioning	62,097	6,334	$18,143	8	-	15	$145,145	-	$272,148
3	Exhaust Fan Scheduling	188,181	0	$30,812	1	-	3	$30,812	-	$92,435
4	Unit Ventilator Scheduling	107,413	2,061	$20,182	1	-	3	$20,182	-	$60,546
5	Exhaust Fan EC Motor Retrofits	23,658	0	$3,874	10	-	15	$38,736	-	$58,104
6	Unit Ventilator EC Motor Retrofits	54,632	0	$8,945	10	-	15	$89,451	-	$134,176
7	Motor Retrofits for VFDs	51,192	0	$8,382	2	-	4	$16,764	-	$33,527
	Total	**608,092**	**8,394**	**$110,136**						
	% of Baseline	*49%*	*7%*	*38%*						

While reviewing the tables above, please note the following:

1. Cost savings are based upon average blended utility rates of $0.16/kWh for electricity and $1.26/therm for natural gas. These utility rates are based on recent electricity and natural gas data provided by National Grid and an assumed natural gas supply rate. Utility rates can be updated upon request.
2. The energy use estimates reflected in the tables above were analyzed independently of each other to provide a more direct comparison of which are worth pursuing as part of a next phase future project. In practice, if multiple measures are implemented concurrently, the net effect would be different (typically less) than the sum of the individual measure estimates. As part of a future phase of analysis, groups of measures could be analyzed together to quantify the net impact of multiple overlapping scopes of work.
3. The energy use estimates in Table 1 above are reflective of using the heat pumps in the high school building to provide heating, but not cooling, in Option 1A and Option 2, since the existing hydronic system provides hot water only. The addition of heat pumps would inherently introduce the ability to provide both heating and cooling, with required infrastructure upgrades, however, utilizing the heat pumps for cooling would result in a significant increase in electric energy use and cost. The cooling capacities of the proposed heat pump systems are estimated for each option based on the required heat pump heating capacity and are presented in Table 1 for informational purposes.
4. Estimates of potential utility incentives have been provided by National Grid and included in Table 1. The incentives shown assume custom incentives for the high school, since total nominal capacity of the heat pump equipment would exceed the prescriptive limit of 150 tons. The incentives shown assume prescriptive incentives for the administration building and wastewater treatment plant.
    a. Please note these estimates may increase or decrease based on final engineering and/or policy analysis, or due to changes to program design, requirements, or incentive levels, which may happen at any time and solely at National Grid's discretion. Also, these incentives are based on current policies and guidelines as set forth by the 3-year energy efficiency plan, which ends on December 31, 2024. Incentives are subject to change at any point in time, particularly if project construction extends beyond that end date.
5. Prescriptive incentives of up to $2,200/unit for heat pump domestic hot water heaters are available for units up to 120 gallons. Refer to the MassSave website for more information. All incentives will be subject to further analysis and rebate amounts are solely determined by the utilities.
6. The preliminary budgetary opinions of probable construction costs for electrification are based on past experience, previous vendor quotes, and industry metrics. The opinions of probable cost presented are a high-level view of the potential costs to screen the economic viability of the project and are not reflective of what would be produced by a

detailed economic feasibility analysis. Refer to the cost sections within the descriptions of each option below for more specific information.

7. The District completed a Comprehensive Capital Plan earlier this year, which lays out a 6-year plan and budget for planned capital projects. The capital plan includes significant HVAC system upgrades, including replacing the boilers, rooftop units, air handling units, heating and ventilating units, unit ventilators, and exhaust fans. It also includes a phased approach to upgrading and expanding the building automation system. Generally, the preliminary budgetary opinions of probable construction costs developed for the electrification options do not include costs already accounted for in the capital plan. Per Masco's request, Table 1 includes a second cost column with the estimated incremental cost of additional work, such as end of life equipment replacements and building wide BMS upgrades. These incremental costs were not estimated by B2Q, but rather were taken directly from Appendix A in Masco's Capital Plan, as noted in Footnote 1 below Table 1. Refer to the cost sections within the descriptions of each option below for more specific information.

8. CO_2 emissions reductions estimates presented in the table above are based on 0.41 lb CO_2/kWh and 11.70 lb CO_2/therm of natural gas, per the Energy and Environmental Affairs directive RE: Greenhouse Gas Emissions Reduction Goal for Mass Save. Note that equivalent CO_2 emissions savings will continue to improve over time if New England continues to make progress toward its goal of decreasing carbon intensity on the electric grid. Therefore, the table also presents the potential CO_2 emissions reductions in the future if there is 100% carbon-free electricity.

FACILITY DESCRIPTION

GENERAL

The Masconomet Regional School is located at 20 Endicott Road in Boxford, MA. The regional school district serves students in grades 7 through 12 from Boxford, Middleton, and Topsfield. The site spans over 90 acres and includes the school building, a wastewater treatment plant, the administration building, and many sports fields.

The school building is 3 stories high and was originally constructed in 1958. In 1972, the administration building was constructed. In 2001, a major renovation was completed on the school building, including the addition of the high school and the wastewater treatment plant. As it stands today, the school building covers over 371,000 square feet. The high school makes up nearly 149,000 square feet, while the middle school and "the link" make up the rest. The wastewater treatment plant is 4,300 square feet and the administration building is 5,000 square feet spanning two floors.

The school building is considered to have three sections – the middle school, the high school, and "the link." The link connects the middle and high school sections, and is home to common spaces including the auditorium, gymnasium, field house, two cafeterias, and kitchen. The high school is served by a dedicated heating hot water system, separate from the middle school and the link. The high school, wastewater treatment plant, and administration building share a common electric utility meter and account but have separate natural gas meters and accounts. The middle school and the link are served by their own heating systems and have separate utility accounts and are therefore considered in a separate study.

MECHANICAL SYSTEMS

The mechanical systems descriptions below are primarily based on information provided in the 100% construction drawings developed in 1999, as well as observations and conversations with facilities staff during the walkthrough performed on September 7, 2023. Based on conversations with facilities staff, copies of the as-built drawings are not available. Additional information was gathered from the 2017 Capital Asset Assessment report and the 2023 Comprehensive Capital Planning Report provided by the District.

HIGH SCHOOL

Heating, cooling, and ventilation are provided to the high school library by air handling unit AHU-3. The AHU is equipped with a hot water (HW) heating coil and a direct expansion (DX) cooling coil with a remote condensing unit (CU) located on the roof. Heating and ventilation are provided to the science rooms by eight (8) ceiling-mounted heating and ventilating (HV) units equipped with HW heating coils. Three (3) rooftop units (RTUs) with HW heating and DX cooling supply air to the high school library and administration areas. The table on the next page summarizes the major air handling equipment.

Table 4: Summary of major air handling equipment.

Tag	Service	Supply Airflow	Min Outside Airflow	Supply Fan Size	Return Fan Size	Fan VFDs	Cooling Type	Heating Type
-	-	cfm	cfm	hp	hp	-	-	-
RTU-10	HS Admin	3,200	950	5	2	Yes	DX	HW
RTU-11	HS Admin	4,200	1,250	5	2	Yes	DX	HW
RTU-12	HS Library	9,320	2,800	10	5	Yes	DX	HW
RTU-17	WWTP Offices	700	175	2	None	No	None	Gas
AHU-3/ ACCU-3	HS Library	18,300	5,500	15	7.5	Yes	DX	HW
HV-1 thru 8	Science	1,500	500	1.5	None	No	None	HW

Space conditioning is provided by a variety of terminal devices. Supply air from AHUs and/or RTUs is provided to variable air volume (VAV) boxes in the library and administration areas. Based on the available construction drawings, some, but not all, of the VAV boxes are equipped with HW reheat coils. Supplemental space heating is provided by HW fin tube radiation (FTR) in most spaces with VAV boxes. The classrooms throughout the high school are heated and ventilated by unit ventilators (UVs). There are also convectors, unit heaters, and cabinet unit heaters to provide HW heating throughout the building in corridors, stairwells, vestibules, storage rooms, and utility rooms.

There are approximately (37) roof-mounted constant speed exhaust fans that serve the high school. The BAS has limited control of the fans and there is currently no schedule tied to them. As a result, the fans all run 24/7. A few EFs were reportedly retrofitted with VFDs but the existing motors are not compatible, so they have since been disconnected and continue to operate at a constant speed. The table on the next page summarizes the exhaust fans in the high school.

Table 5: Summary of exhaust fans.

Tag	Service	Exhaust Airflow	Exhaust Fan Size
-	-	cfm	hp
EF-1	General Exhaust	2,600	1
EF-2	General Exhaust	2,800	1
EF-3	General Exhaust	2,775	1
EF-4	General Exhaust	1,500	0.5
EF-5	Toilet/ Showers	5,400	1.5
EF-6	Toilet/ Showers	5,400	1.5
EF-7	Gym	3,500	0.75
EF-8	Gym	3,500	0.75
EF-9	Toilet/ Showers	2,200	0.75
EF-10 A	Toilet/ Showers	100	80 W
EF-10 B	Toilet/ Showers	100	81 W
EF-10 C	Toilet/ Showers	100	82 W
EF-27	Toilets	2,200	0.75
EF-28	General Exhaust	3,250	0.75
EF-29	Toilets	600	0.25
EF-30	General Exhaust	3,575	1.5
EF-31	General Exhaust	3,150	1
EF-32	Toilets	800	0.25
EF-33	General Exhaust	3,150	0.75
EF-34	Toilets	2,200	0.75
EF-35	General Exhaust	10,075	7.5
EF-36	Toilets	1,500	0.5
EF-37	General Exhaust	8,425	5
EF-38	Kiln Exhaust (HS)	500	0.25
EF-39	Art Purge (HS)	500	0.25
EF-40	Art Purge (HS)	500	0.25
EF-41	Dark Room (HS)	1	0.33
EF-54	Chemistry SL Fume Hoods	1,200	0.5
EF-55	Chemistry SL Fume Hoods	1,200	0.5
EF-56	Toilet/ Janitor	300	0.25
EF-57	Art Room (HS)	500	0.25
EF-59	Vented Storage Cabinet	400	0.33
EF-60	Chemistry SL Fume Hoods	1,200	0.5
EF-61	Chemistry SL Fume Hoods	1,200	0.5
EF-65	Vented Storage Cabinet	100	0.25
EF-66	Vented Storage Cabinet	100	0.25
EF-67	Vented Storage Cabinet	100	0.25

Two (2) 4,640 MBH output Weil McLain boilers, Boiler 3 and 4, provide hot water (HW) to the air handling and terminal equipment throughout the high school. The boilers are over 20 years old and were installed during the addition of the high school. Facilities staff indicated that the boilers are approaching the end of their useful life. Five of the sections in Boiler 1 have experienced leaks in recent years. The boilers are enabled seasonally, typically from October through May. Facilities staff manually adjust the HW supply temperature and indicate its typically set to 150°F during mild weather and 180°F during colder weather.

Table 6: Summary of boilers.

Tag	Input Capacity, each	Output Capacity, each	Thermal Efficiency
-	MBH	MBH	-
Boiler 3 & 4	5,845	4,640	79%

HW is distributed by two (2) 570 GPM, 20-hp pumps, P-3 and P-4. The pumps operate in lead/lag fashion and are manually rotated once a week by facilities staff. The pumps were retrofitted with VFDs, but due to recent controls and/or maintenance issues, the VFDs are currently running in hand at 30 Hz, which equates to 50% speed. The lead HW pump runs 24/7 whenever the boilers are enabled during heating season. Facilities staff reported that P-3 has failed, so P-4 runs as the lead pump throughout the heating season.

Table 7: Summary of pumps.

Tag	Service	Design Flow	Design Head	Horse-power
-	-	gpm	ft	hp
P-3 & 4	HW Supply	570	85	20

ADMINISTRATION BUILDING

The first floor of the building is heated and cooled by a residential-style air handler mounted in the ceiling, with a split-style condensing unit located outside at-grade. Based on available nameplate information, the air handler is rated for 5 tons of cooling and 112 MBH of heating. According to facilities staff, the air handler cannot keep up with cooling demands in the summer, resulting in the use of supplementary, portable air conditioners. It does not appear that the air handler provides ventilation.

The basement is ventilated by an energy recovery ventilator (ERV) located outside at-grade. ERV-1 was recently replaced around 2020. ERV-1 is equipped with an enthalpy wheel for energy recovery but does not feature any other sources of heating or cooling to condition the 100% outside air. Facilities staff noted that the unit is manually disabled during the summer and winter to avoid occupant comfort issues.

There are also approximately 10 – 12 wall recessed electric unit heaters and electric baseboard heaters on the basement and first floor for space heating. The electric heaters are controlled by manual dial thermostats, which are reportedly not scheduled or turned off when occupants leave the building at the end of each day during the winter.

Wastewater Treatment Plant

The wastewater treatment plant (WWTP) is primarily heated by four (4) gas fired, ceiling hung unit heaters. Facilities staff added Wi-Fi thermostats for space temperature control and reportedly maintain the plant at 80°F during heating season. One (1) rooftop unit, RTU-17, with gas heating and DX cooling supplies air to the office and corridor in the building. There is also an electric, ceiling hung unit heater in the electric/emergency generator room.

Domestic Hot Water Systems

High School

Domestic hot water (DHW) is provided to sinks for hand washing throughout the building. DHW for the high school is provided by a 399 MBH input gas fired AquaPLEX DHW heater, which is estimated to have been installed around 2018. The DHW heater has an integral 125-gallon storage tank. A second DHW heater with a similar storage capacity was observed on site but noted to be drained and retired in place by facilities staff.

Administration Building

DHW is provided to sinks for hand washing in the building. DHW for the administration building is provided by a 28-gallon electric DHW heater tank.

Controls Systems

The mechanical systems in the buildings are controlled by a variety of controls systems, as described below:

1. Pneumatic controls – Based on conversations with facilities staff, a majority of terminal equipment and control actuators throughout the building still have pneumatic controls. This includes all the unit ventilators, VAV boxes, and fin tube radiation, which are controlled by pneumatic thermostats. Facilities staff noted that the unit ventilator HW valves are always 100% open, while face and bypass dampers modulate to maintain the space temperature setpoint.
2. Johnson Controls Metasys building automation system (BAS) – Based on conversations with facilities staff, a small portion of the HVAC equipment in the building has direct digital controls (DDC) and/or electronic-to-pneumatic (E-P) controls.
    a. Includes Metasys equipment controllers throughout the building. Facilities staff noted that this product line is obsolete.
    b. Includes a MicroTech controller to integrate with McQuay rooftop unit 3rd party controllers. Facilities staff noted that this controller is obsolete and is not capable of interfacing with newer Daikin McQuay control boards.
    c. Includes a Metasys Integrator to integrate with other 3rd party equipment controllers.

d. Includes a Johnson Controls Facility Explorer supervisory controller, enabling a web-based graphical user interface. HVAC equipment observed on the BAS graphics includes AHU-3; RTU-10, 11, 12; and HV-1 through 8.

3. Heat Timer standalone controller for boiler plant.
4. Programmable Wi-Fi Honeywell thermostats for the administration building and wastewater treatment plant.
5. Manual dial controls for administration building electric resistance heaters.

Utility Information

Utilities

Electricity Delivery: National Grid

Natural Gas Delivery: National Grid

The graphs and discussion on the following pages are based on electric and natural gas utility data provided by National Grid from January 2020 through May 2023.

Monthly Energy Use

The graph below illustrates the monthly electric consumption from January 2020 through May 2023 and the peak electric demand in 2022. Note that the graph below represents the combined electric use and peak demand for the high school, administration building, and the WWTP. The electric use and demand are consistent year-round as there is limited cooling equipment in the school. The lower use in 2020 is likely the result of reduced occupancy during the COVID-19 pandemic.

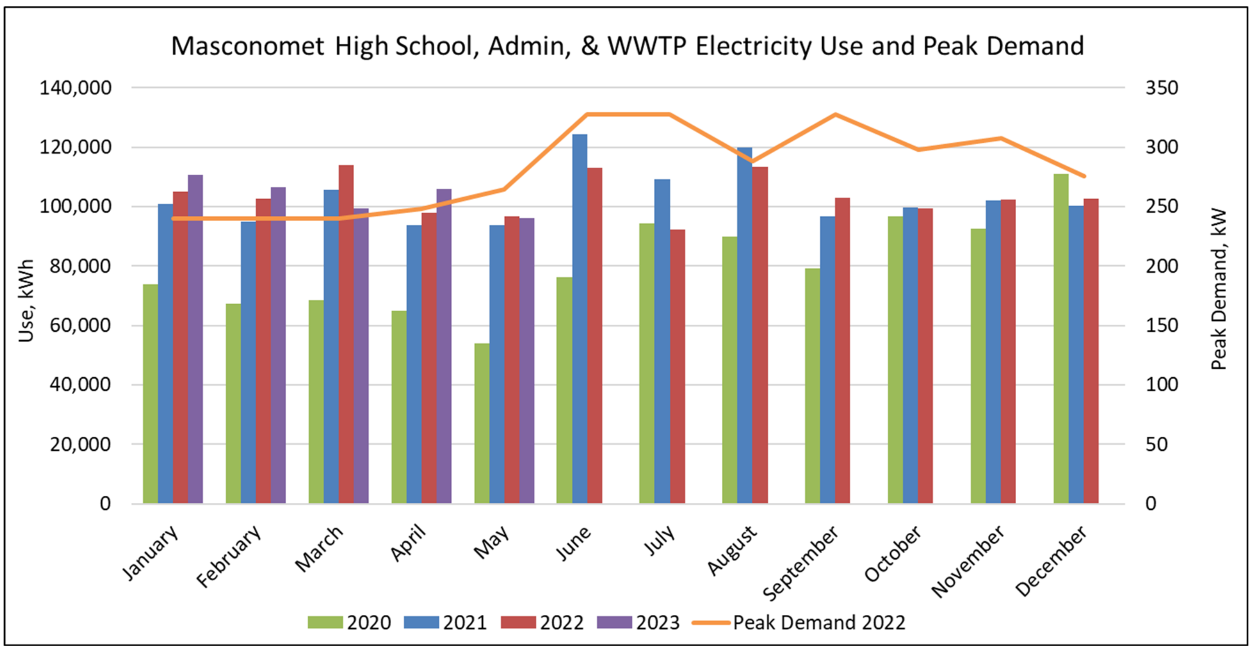


Figure 1: Monthly electric usage.

The graph below illustrates the monthly natural gas consumption from January 2020 through May 2023 for the high school, only. There is a strong weather correlation with the highest consumption during the heating season. This is the result of the boilers and the building's hot water heating system. The building's baseline natural gas usage can be seen June through September. This is the result of the small, year-round domestic hot water load. Similar to the electric use above, the low natural gas use seen February 2020 through April 2020 can likely be attributed to the COVID-19 pandemic.

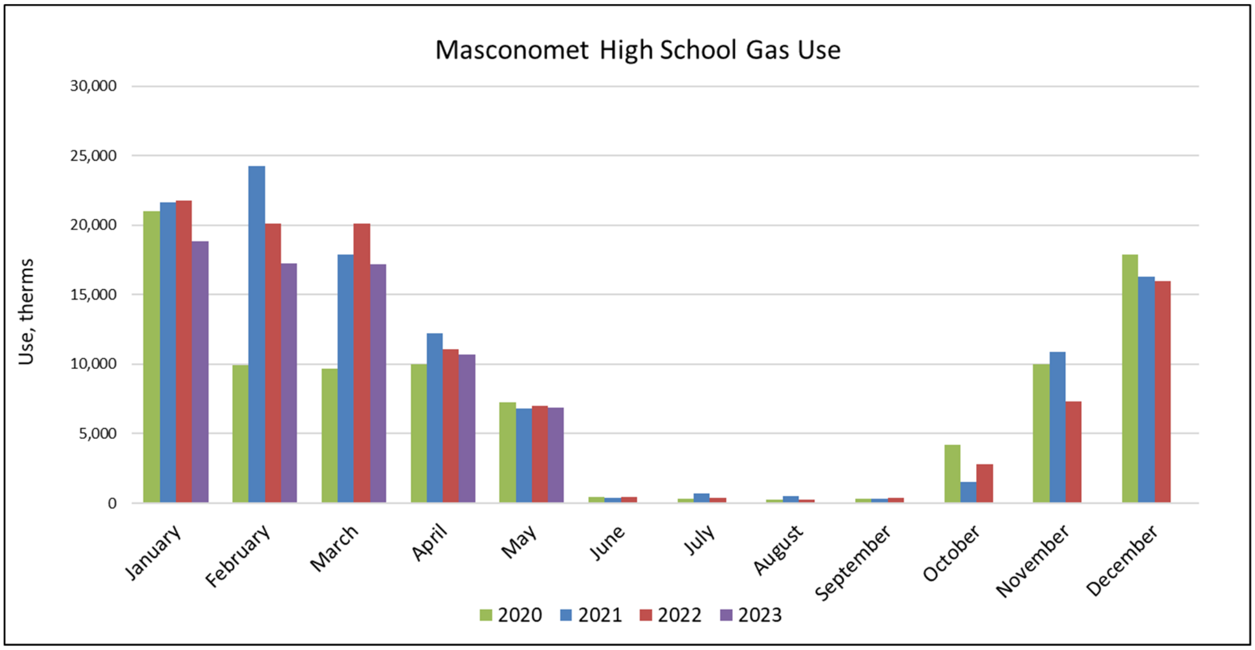


Figure 2: Monthly natural gas usage for the high school.

The graph below illustrates the monthly natural gas consumption from January 2020 through May 2023 for the WWTP, only. There is a strong weather correlation with the highest consumption during the heating season. This is primarily the result of the gas fired unit heaters used to heat the plant. Gas use is trending noticeably higher in 2022 and 2023, compared to 2020 and 2021, which may be a result of changes in temperature setpoints or operating setpoints.

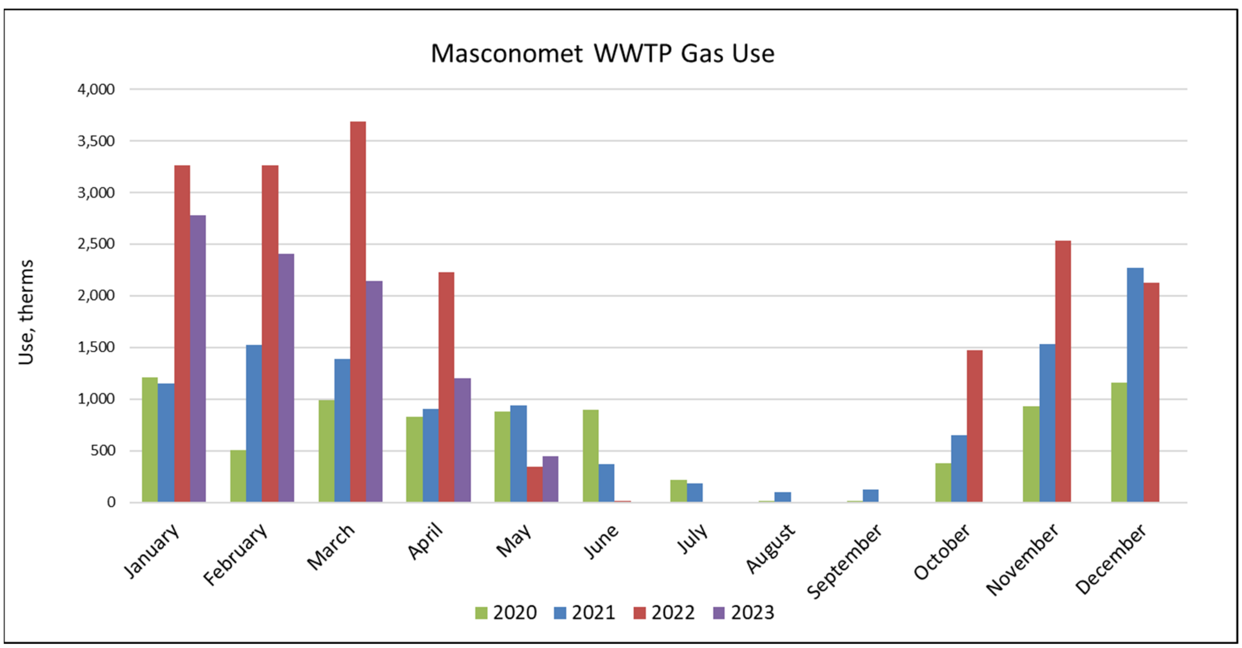


Figure 3: Monthly natural gas usage for the wastewater treatment plant.

The graph below illustrates the monthly natural gas consumption from September 2021 through May 2023 for the administration building, only. Natural gas use follows weather related patterns with increased use during the heating season. There is no gas use during the summer, as domestic hot water is provided by an electric heater. The only use of natural gas in the building is the residential-style air handler meeting some of the heating demands of the first floor. Gas use in January through May was noticeably higher in 2022 than 2023, which may be attributable to use of electric resistance heaters as the primary source of heat, rather than the air handler.

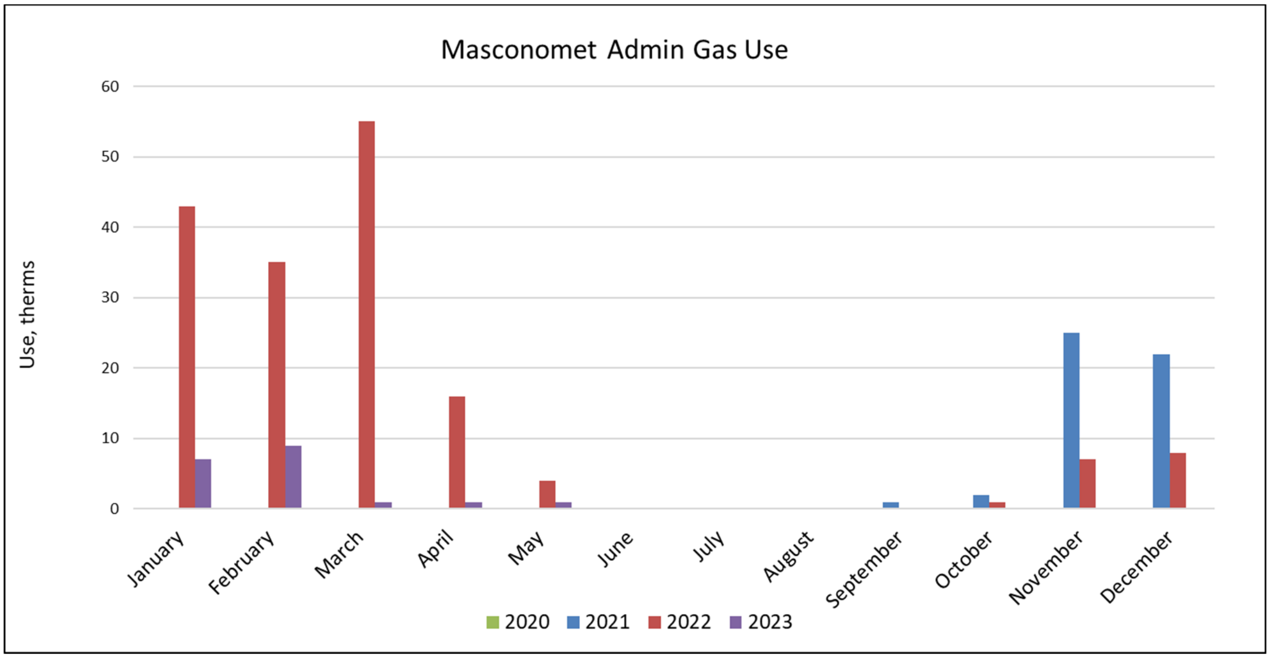


Figure 4: Monthly natural gas usage for the administration building.

ANNUAL ENERGY BENCHMARKING

The table below summarizes the annual combined energy use and energy use intensity (EUI) for the high school, administration building, and WWTP from 2020 through 2022. According to the 2018 Commercial Buildings Energy Consumption Survey (CBECS) conducted by the US Energy Information Administration, the average building EUI in New England is 74 kBtu/ft^2. The average EUI for education buildings is 64.1 kBtu/ft^2. The total annual EUI was 110.9 kBtu/ft^2 in 2022, about 73% higher than the average education building in the US. The building's high energy usage is likely attributable to the age of the equipment in the building, limited equipment control, and 24/7 schedule of much of the HVAC equipment. Recommendations to reduce this usage can be found in the sections below.

Table 8: Annual energy usage and energy use intensity (EUI).

Time Period	Total Electric	Total Gas	Electric EUI	Gas EUI	Total EUI
-	kWh	Therms	kBtu/sf	kBtu/sf	kBtu/sf
2020	967,800	113,451	21.8	74.9	96.6
2021	1,240,200	128,942	27.9	85.1	113.0
2022	1,241,934	125,668	28.0	82.9	110.9

HVAC Electrification Options

The potential electrification options evaluated during this scoping study are described on the following pages. The options discussed are provided as a high-level view of the potential energy savings and costs and are not reflective of what would be produced by a detailed investment grade conceptual design and economic feasibility analysis. Emissions, energy, and cost savings were calculated using high-level estimates based on existing equipment capacities, actual electric and natural gas usage, past experience, published heat pump performance, and typical industry metrics. High level opinions of probable construction costs were estimated based on industry-standard cost estimating guides, as well as past experience and previous budget quotes from equipment vendors and contractors.

Electrification Feasibility Considerations

Determining the feasibility of an electrification option is a complex effort that should account for multiple interactive factors. As shown in Figure 5 below, these factors include the solution availability, technical requirements, site specific conditions, implementation costs, and societal pressures. This study consists of a high-level review of heat pump feasibility, with a focus on technical factors and site-specific conditions. Further evaluation of feasibility based on societal factors, project cost, and the long-term goals of the Owner, in conjunction with the findings in this report, is recommended.

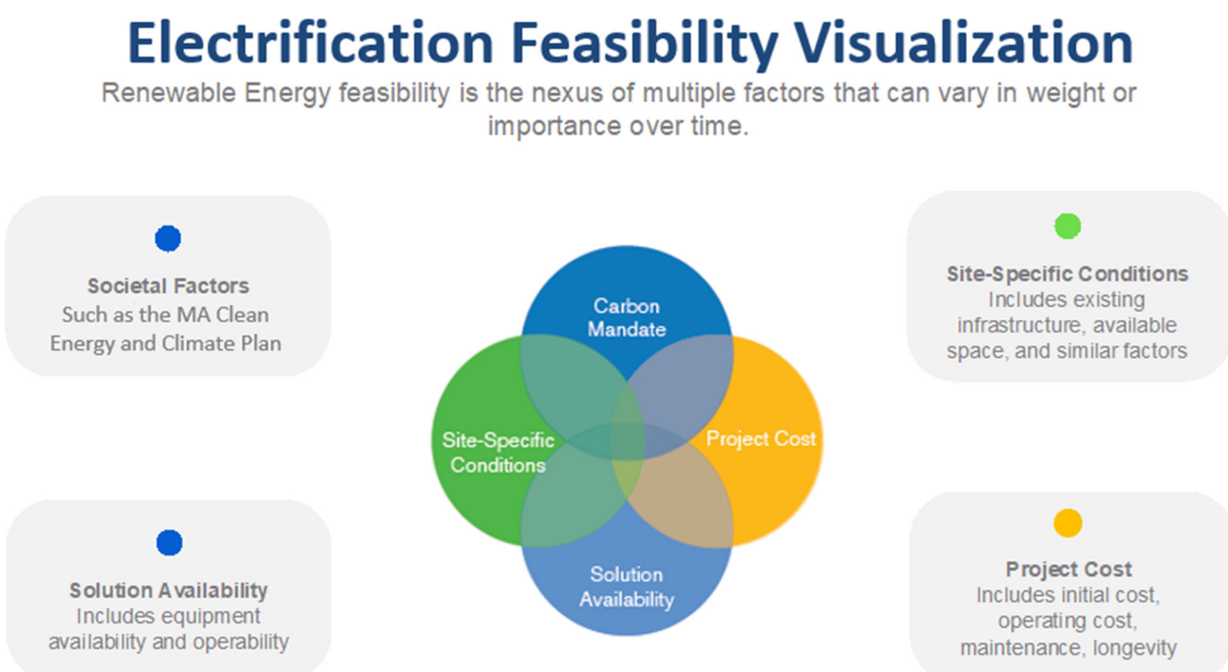


Figure 5: Visualization of prominent electrification feasibility considerations

Technologies Considered

The following section provides a brief description of each heat pump technology considered in this study. The table below summarizes the general advantages and disadvantages of each technology, which may or may not apply to this specific site.

Option	Advantages	Disadvantages
Air-to-Air VRF Heat Pumps	• Limited need for supplementary boiler operation (may still be needed for backup during power outage) • Potential for full electrification of space heating • Independent of existing infrastructure and terminal equipment, which is approaching end of life in some cases • Wall/ceiling mounted units may not conflict with the locations of existing heating infrastructures, allowing it to remain as backup • Relatively better efficiency than air-to-water options at lower ambient conditions because of reduced compressor lift	• Increased points of failure/pieces of equipment to maintain from small, distributed equipment • Potential safety/maintenance concern of refrigerant in occupied spaces • Potential for exposed equipment and piping, which may impact building aesthetics • Relatively low capacity per heat pump circuit, meaning that there would need to be over a dozen condensing units and other components to serve a building this large • Required addition of Energy Recovery Ventilators (ERVs) to provide required ventilation to classrooms separate from heat pumps depending on configuration considered • New ductwork for ventilation (where required), which also may require architectural modifications to the building
Air-to-Air Heat Pump Rooftop Units	• Reuse existing ductwork • Minimal roofing or structural modifications in many cases • Improved cooling efficiency over existing RTUs with DX cooling • Existing natural gas connections could be reused for dual fuel heat pumps with natural gas as secondary source of heat	• Potential need for supplementary electric infrastructure • Secondary heat source likely required due to heating capacity decreases during low-temperature operation; options include natural gas (dual fuel) or electric resistance heat • New natural gas connections would need to be added for existing RTUs with HW heating, if

		using dual fuel as secondary heat source • Increased electrical requirements, if using electric resistance as secondary heat source • Difficult to incorporate heat recovery into existing infrastructure constraints
Central Air-to-Water Heat Pump	• Boilers (either new or existing) could be tied into HW system for supplementary or backup heating • Single piece of heat pump equipment to operate and maintain	• Limited low-temperature operation (i.e., <0°F ambient); backup boiler use still required on coldest days • Efficiency decreases significantly as outside air temperature decreases, even as compared with other heat pump technologies • Heating capacity decreases as outside air temperature decreases, even as compared with other heat pump technologies

Air-to-Air Heat Pumps

Air-to-Air Heat Pumps, also known as air-source heat pumps, directly transfer heat to and from outside air to the spaces served. Heat pumps can operate during both the summer to provide cooling and the winter to provide electrically-sourced heating.

VRF Heat Pumps

Air-to-air heat pump indoor units and outdoor condensing units can be connected 1-to-1 or configured to use one outdoor condensing unit for multiple indoor units. There are also variable refrigerant flow (VRF) systems where one outdoor condensing unit could be connected to as many as 50 indoor units, depending on the equipment. Indoor units can range from wall-mounted units, ducted and non-ducted ceiling cassettes or fan coil units, or floor-mounted units. Condensing units can also be integrated with heat pump coils in air handling units via linear expansion valve (LEV) kits. Condensing units for VRF systems can be capable of operating at low ambient temperatures, depending on the equipment, and therefore VRF heat pumps could be designed to meet most or all a building's space heating needs, as compared with other technologies described below. On the other hand, it is often advisable to maintain a non-electric backup heating source in the event of extreme cold (e.g., less than -10°F) or power outage.

Packaged Heat Pump RTUs

Packaged air-source heat pump rooftop units can be installed in place of traditional rooftop units. Packaged heat pump RTUs are typically offered with a secondary source of heat for supplementary heating during low-temperature operation or backup in the event equipment malfunction. Secondary heat sources typically come in the form of an electric resistance heating element or a natural gas-fired furnace. Dual fuel heat pump RTUs typically have smaller electrical requirements than heat pump RTUs with electric resistance backup, often leading to no or limited cost to upsize the electrical circuit breaker and feeders to the unit. Existing traditional RTUs can often be swapped out with package heat pump RTUs with minimal roof, structural, or duct modifications, though careful engineering is required to verify such details during the design process.

Central Air-to-Water Heat Pump

Central air-to-water heat pumps transfer heat from outside air to a water loop. Where air-to-air systems are comparable to DX cooling, air-to-water systems are comparable to an air-cooled chiller, where a refrigerant cycle is used to transfer heat from the air to a water loop, and vice versa, and then the water is distributed throughout the building to heat or cool supply air at the air-handler and zone level via hydronic coils. Typically, this option is attractive for buildings with existing hot water or dual temperature infrastructure, due to the potential ability to reuse existing infrastructure and retain boilers for supplementary heating.

Air-to-water heat pumps typically have reduced capacities and lower efficiencies as the ambient temperature decreases, and as the hot water supply temperature increases, as compared with other heat pump technologies that are less significantly affected. Further, air-to-water heat pumps are typically able to provide 120 – 140°F hot water or lower, whereas traditional existing hot water infrastructure and equipment are typically selected based on higher temperature hot water temperature (i.e., 180 – 200°F). As a result, fossil fuel-fired heating systems typically must remain to supplement heating in the coldest weather, limiting the potential for full heating system electrification, if the existing hot water coils and terminal equipment are not replaced/upsized.

Option 1A: Air-to-Air VRF Heat Pumps

Economics Summary

Table 9: Option 1A Economic Summary.

Proposed Electrification Option		Estimated Heat Pump Heating Capacity	Estimated Heat Pump Cooling Capacity	Estimated Annual Electric Savings	Estimated Annual Fossil Fuel Savings	Estimated Annual Energy Cost Savings	Electrification Opinion of Probable Cost
		tons	tons	kWh	therms	$	$
Option 1A:	VRF Heat Pumps, High School	387	338	-866,820	96,073	-$20,876	$4,463,450
Option 1A:	VRF Heat Pumps, Administration	18	15	47,517	169	$7,993	$280,900

Overview

This option proposes to install air-to-air VRF heat pump systems throughout the high school and the administration building. This would involve the installation of new indoor units, such as wall-mounted or ceiling-suspended units, in the classrooms and offices.

Because the existing unit ventilators would no longer serve as the primary heating system, new ventilation systems would be required in parallel with the new VRF system for the classrooms. The most efficient option generally is to utilize energy recovery ventilators (ERVs). This equipment utilizes dedicated supply and exhaust fans to provide code minimum ventilation airflow in tandem with a fixed polymer “core” heat exchanger that uses exhaust air to pre-heat fresh air in the winter and pre-cool it in the summer. The ERVs could be located on the roof or at-grade and ducted throughout the building above the existing suspended ceilings to distribute ventilation throughout. Preliminary calculations from this study suggest that (4) 6,000 cfm ERVs could be sufficient to satisfy the building’s requirements, though further engineering is required.

Note that there are options on the market for packaged air-source heat pump unit ventilators that could be a direct replacement for the existing HW unit ventilators; however, our experience has found that they generally only come in packaged options, which is expected to be less energy efficient than a bigger, networked VRF system and would involve a significantly higher installation cost, especially because of the requirement to provide new enhanced electrical distribution to all areas of the building.

The AHUs and HVs could receive new refrigerant coils with LEV kits to integrate with the VRF system. The new heat pump refrigerant coils could meet the heating requirements of all units, as well as the cooling requirements of AHU-3, instead of the existing DX cooling coil.

New heat pump outdoor units serving the indoor units and AHU/HV refrigerant coils would be mounted outside, either on the roof or at-grade. Further review by a licensed structural engineer would be required to assess the condition of the roof for the ability to accept new loads.

The electrification opinion of probable construction cost below includes no demolition, meaning we assume the hot water system, including the unit ventilators and fin tube radiation, would either be kept operation as a backup or be abandoned in place. It is advisable to have a reliable source of backup heat that is separate from the heat pumps, such as a gas-fired boiler, furnace, or electric resistance heat on standby power, to protect the building in the event of a power outage or extreme cold that is below the operating range of the heat pumps.

Please note the energy impacts in the table do not include the effect of adding air conditioning to the entire building, but rather only reflects the existing, limited use of air conditioning in certain spaces. Also, please note that the energy impacts shown in the table for the administration building assume that the new heat pumps would meet the heating requirements of the basement and first floor, instead of the existing electric resistance heaters.

OPINION OF PROBABLE CONSTRUCTION COST

Table 10: Option 1A High School Opinion of Probable Construction Budget Cost.

Category	Estimated Budget
Demolition	$0
HVAC Equipment	$959,600
HVAC Piping, Ductwork, Other Materials	$440,000
HVAC Installation	$731,850
Electrical Branch Circuit Materials and Labor[1]	$159,000
Startup, Commissioning, TAB, Closeout	$323,600
Controls	$82,000
Engineering	$350,800
Envelope Penetrations, Patching, Firestopping	$331,800
Contractor General Conditions & PM Labor	$382,700
Contractor Overhead & Profit	$286,100
Contingency	$416,000
Grand Total	**$4,463,450**

[1] Budget assumes no change in main electrical service and distribution. Further engineering needed to confirm and/or estimate costs

Table 11: Option 1A Administration Opinion of Probable Construction Budget Cost.

Category	Estimated Budget
Demolition	$3,900
HVAC Equipment	$29,400
HVAC Piping, Ductwork, Other Materials	$10,000
HVAC Installation	$34,400
Electrical Branch Circuit Materials and Labor[1]	$10,600
Startup, Commissioning, TAB, Closeout	$44,500
Controls	$36,000
Engineering	$22,600
Envelope Penetrations, Patching, Firestopping	$25,200
Contractor General Conditions & PM Labor	$24,600
Contractor Overhead & Profit	$13,000
Contingency	$26,700
Grand Total	**$280,900**

[1] Budget assumes no change in main electrical service and distribution. Further engineering needed to confirm and/or estimate costs

Note the cost estimate in the table above is related to the electrification portions of the project, only. Refer to Table 1 in the executive summary for possible incremental costs for additional HVAC and controls upgrades, provided in Masco's capital plan. The cost estimates above are meant to provide a high-level opinion of probable cost, and is based on the following assumptions:

- New condensing units and ERVs can be installed on the roof with minimal roofing and structural work.
- There is sufficient space above suspended ceilings to route refrigerant piping and ERV ductwork and a chase could be found or built to distribute piping and/or ductwork between floors.
- The existing HW system would be abandoned in place or remain as backup.
- The existing electric resistance heaters in the administration building would be abandoned in place or remain as backup.
- Existing to remain mechanical and electrical equipment is in proper working order and would not need to be upgraded for normal operations and maintenance reasons.
- A new building automation system would already be installed per the ECM below and the existing capital improvement plan. See Table 1 in the executive summary for the estimated incremental costs of these replacements, as taken from Appendix A of the capital improvement plan.
- Excludes the cost to upgrade the building's electrical service and primary electrical infrastructure, as it appears it could be possible to incorporate the new electrification loads within the existing service capacity; however, this is a high-level assessment, and it

is recommended that a licensed professional electrical engineer more thoroughly evaluate the existing infrastructure in preparing for any future phases of design and construction of new heat pump systems.

- No upgrades to the existing standby power system or generator.
- No correction of existing code violations, structural insufficiencies, or hazardous materials.

Given the volatile nature of construction costs in the current market, we recommend that the above estimates be considered preliminary budgets for purposes of vetting whether this building is a good candidate to proceed to the next phase of the process. In general, projects with a full set of design drawings and specifications are expected to have actual contractor bids within +/- 10 – 15% of a third-party cost estimator's projection. In this case, where the proposed system has not been designed, actual costs could vary by a much wider margin and the final design scope is likely to change and be refined as further investigation and coordination are completed in subsequent design phases.

OPTION 1B: AIR-TO-AIR HEAT PUMP RTUS

ECONOMICS SUMMARY

Table 12: Option 1B Economic Summary.

Proposed Electrification Option		Estimated Heat Pump Heating Capacity	Estimated Heat Pump Cooling Capacity	Estimated Annual Electric Savings	Estimated Annual Fossil Fuel Savings	Estimated Annual Energy Cost Savings	Electrification Opinion of Probable Cost
		tons	tons	kWh	therms	$	$
Option 1B:	RTU Air-to-Air Heat Pump, High School	59	52	-32,561	5,959	$2,177	$558,338
Option 1B:	RTU Air-to-Air Heat Pump, WWTP	51	45	-147,062	18,002	-$1,396	$763,888

OVERVIEW

This option proposes to replace the existing (3) HW heating/DX cooling RTUs at the high school and the existing (1) gas heating/DX cooling RTU at the WWTP with packaged heat pump RTUs. This option also considers installing new packaged heat pump RTUs to heat the treatment rooms and maintenance room in the WWTP, instead of the existing gas fired unit heaters.

Heat pump RTUs are typically equipped with a secondary source of heating for low ambient operation, either electric resistance or gas heating. The calculations assumed that gas-fired backup heating would be used as necessary to provide supplementary heating during low-temperature heating. Gas options generally require less first cost to update the electrical circuit breakers and feeders, compared to electric resistance options.

OPINION OF PROBABLE CONSTRUCTION COST

Table 13: Option 1B High School Opinion of Probable Construction Budget Cost.

Category	Estimated Budget
Demolition	$10,200
HVAC Equipment	$162,000
HVAC Piping, Ductwork, Other Materials	$25,688
HVAC Installation	$25,350
Electrical Branch Circuit Materials and Labor[1]	$23,400
Startup, Commissioning, TAB, Closeout	$62,500
Controls	$41,000
Engineering	$40,400
Contractor General Conditions & PM Labor	$77,100
Contractor Overhead & Profit	$38,100
Contingency	$52,600
Grand Total	**$558,338**

[1] Budget assumes no change in main electrical service and distribution. Further engineering needed to confirm and/or estimate costs

Table 14: Option 1B Wastewater Treatment Plant Opinion of Probable Construction Budget Cost.

Category	Estimated Budget
Demolition	$3,400
HVAC Equipment	$162,000
HVAC Piping, Ductwork, Other Materials	$98,438
HVAC Installation	$69,150
Electrical Branch Circuit Materials and Labor[1]	$31,200
Startup, Commissioning, TAB, Closeout	$85,400
Controls	$41,000
Engineering	$55,500
Contractor General Conditions & PM Labor	$96,300
Contractor Overhead & Profit	$49,200
Contingency	$72,300
Grand Total	**$763,888**

[1] Budget assumes no change in main electrical service and distribution. Further engineering needed to confirm and/or estimate costs

Note the cost estimate in the table above is related to the electrification portions of the project, only. Refer to Table 1 in the executive summary for possible incremental costs for additional

HVAC and controls upgrades, provided in Masco's capital plan. The cost estimates above are meant to provide a high-level opinion of probable cost, and is based on the following assumptions:

- Existing ductwork and roof curbs can be reused.
- Existing gas fired unit heaters in the WWTP would be abandoned in place or remain as backup.
- Existing to remain mechanical and electrical equipment is in proper working order and would not need to be upgraded for normal operations and maintenance reasons.
- Existing gas meter has sufficient capacity for new loads for the (3) rooftop units which currently use hot water heating, instead of gas heating. Includes allowance for adding new gas piping to the roof.
- A new building automation system would already be installed per the ECM below and the existing capital improvement plan.
- Excludes the cost to upgrade the building's electrical service and primary electrical infrastructure, as it appears it could be possible to incorporate the new electrification loads within the existing service capacity; however, this is a high-level assessment, and it is recommended that a licensed professional electrical engineer more thoroughly evaluate the existing infrastructure in preparing for any future phases of design and construction of new heat pump systems.
- No upgrades to the existing standby power system or generator.
- No correction of existing code violations, structural insufficiencies, or hazardous materials.

Given the volatile nature of construction costs in the current market, we recommend that the above estimates be considered preliminary budgets for purposes of vetting whether this building is a good candidate to proceed to the next phase of the process. In general, projects with a full set of design drawings and specifications are expected to have actual contractor bids within +/- 10 – 15% of a third-party cost estimator's projection. In this case, where the proposed system has not been designed, actual costs could vary by a much wider margin and the final design scope is likely to change and be refined as further investigation and coordination are completed in subsequent design phases.

OPTION 2: CENTRAL AIR-TO-WATER HEAT PUMP

ECONOMICS SUMMARY

Table 15: Option 2 Economic Summary.

Proposed Electrification Option		Estimated Heat Pump Heating Capacity	Estimated Heat Pump Cooling Capacity	Estimated Annual Electric Savings	Estimated Annual Fossil Fuel Savings	Estimated Annual Energy Cost Savings	Electrification Opinion of Probable Cost
		tons	tons	kWh	therms	$	$
Option 2:	Central Air-to-Water Heat Pump, High School	387	338	-930,772	97,481	-$29,573	$3,932,225

OVERVIEW

This option considers installing a new, central air-to-water heat pump to provide low temperature hot water to the high school. When space heating demands are high and/or the ambient temperature is low enough that the heat pump cannot operate (i.e., <0°F), gas-fired boilers would be required to supplement the air-to-water heat pump capacity and provide higher temperature hot water. New air-to-water heat pump modules could be placed outside either at grade or on the roof. Further review by a licensed structural engineer would be required to assess the condition of the roof for the ability to accept new loads.

The electrification opinion of probable construction cost below does not include the cost of demolition or new equipment related to the UVs, AHUs, HVs, FTR, or UHs, as the District has already accounted for the cost to replace this equipment in their capital plan. If the District is interested in pursuing Option 2 further, then it is recommended to consider replacements with low temperature HW coils to be future-ready for use with a new air-to-water heat pump and to minimize the use of gas-fired boilers for supplemental heating.

Also, the electrification opinion of probable construction cost below does not include the cost to demolish or replace the existing boilers, or pumps, as the District has already accounted for the cost to replace this equipment in their capital plan.

Facilities staff expressed concerns about the condition of the existing HW distribution piping, noting historical issues with leaks. Based on the request to assume that the existing distribution should not be reused, the opinion of probable construction cost below includes the cost to demolish and replace the existing HW supply and return piping. Installing new piping would also present the opportunity to properly size the piping to match the design temperature differential (ΔT) of the air-to-water heat pump, which is typically 10-16°F, compared to the existing infrastructure which was designed for a 20°F ΔT. Operating at a lower ΔT relative to typical gas-fired boilers is recommended by heat pump manufacturers to suit the performance of the equipment, but it increases flow requirements to meet the same heating load, so the new piping would likely need to be upsized to accommodate more flow.

Please note the energy impacts in the table do not include the effect of adding air conditioning to the entire building. Also, this option does not include the energy impacts of the existing, limited use of air conditioning in certain spaces. See Option 1A and 1B above for potential air-to-air heat pump options for the (3) RTUs and (1) AHU with existing DX cooling systems.

Please note that the energy impacts and the cost estimates do not consider the administration building or WWTP, due to the lack of existing hydronic infrastructure. See Option 1A and 1B above for the air-source heat pump options proposed for these two satellite buildings.

OPINION OF PROBABLE CONSTRUCTION COST

Table 16: Option 2 High School Opinion of Probable Construction Budget Cost.

Category	Estimated Budget
Demolition	$128,250
HVAC Equipment	$1,100,000
HVAC Piping, Ductwork, Other Materials	$427,500
HVAC Installation	$163,075
Electrical Branch Circuit Materials and Labor[1]	$178,000
Startup, Commissioning, TAB, Closeout	$368,900
Controls	$72,000
Envelope Penetrations, Patching, Firestopping	$200,000
Engineering	$353,800
Contractor General Conditions & PM Labor	$326,600
Contractor Overhead & Profit	$259,200
Contingency	$354,900
Grand Total	**$3,932,225**

[1] Budget assumes no change in main electrical service and distribution. Further engineering needed to confirm and/or estimate costs

Note the cost estimate in the table above is related to the electrification portions of the project, only. Refer to Table 1 in the executive summary for possible incremental costs for additional HVAC and controls upgrades, provided in Masco's capital plan. The cost estimate above is meant to provide a high-level opinion of probable cost, and is based on the following assumptions:

- The existing hot water distribution piping would be demolished.
- New hot water piping can utilize existing chases.
- There is sufficient space for the air-to-water heat pump that is accessible and structurally acceptable.
- Existing to remain mechanical and electrical equipment is in proper working order and would not need to be upgraded for normal operations and maintenance reasons.
- Excludes the cost to replace boilers, pumps, UVs, AHUs, HVs, FTR, or UHs, which would already be installed per the existing capital improvement plan. See Table 1 in the executive summary for the estimated incremental costs of these replacements, as taken from Appendix A of the capital improvement plan.
- Excludes any incremental costs associated with adding low temperature hot water coils in new equipment installed per the existing capital improvement plan (i.e., coils in AHUs, HVs, and UVs).
- Excludes the cost to recharge glycol in the hydronic system, which would already be done per the existing capital improvement plan.
- A new building automation system would already be installed per the ECM below and the existing capital improvement plan. See Table 1 in the executive summary for the

estimated incremental costs of these replacements, as taken from Appendix A of the capital improvement plan.

- Excludes the cost to upgrade the building's electrical service and primary electrical infrastructure, as it appears it could be possible to incorporate the new electrification loads within the existing service capacity; however, this is a high-level assessment, and it is recommended that a licensed professional electrical engineer more thoroughly evaluate the existing infrastructure in preparing for any future phases of design and construction of new heat pump systems.
- Assumes no added cost for sound attenuation.
- No upgrades to the existing standby power system or generator.
- No correction of existing code violations, structural insufficiencies, or hazardous materials.

Given the volatile nature of construction costs in the current market, we recommend that the above estimates be considered preliminary budgets for purposes of vetting whether this building is a good candidate to proceed to the next phase of the process. In general, projects with a full set of design drawings and specifications are expected to have actual contractor bids within +/- 10 – 15% of a third-party cost estimator's projection. In this case, where the proposed system has not been designed, actual costs could vary by a much wider margin and the final design scope is likely to change and be refined as further investigation and coordination are completed in subsequent design phases.

DOMESTIC HOT WATER HEAT PUMP

As part of this effort, B2Q also reviewed the potential to replace the existing natural gas-fired domestic hot water heating system in the high school with a DHW heat pump.

ECONOMICS SUMMARY

Table 17: DHW Heat Pump Economic Summary.

Proposed Electrification Option	Estimated Heat Pump Heating Capacity	Estimated Heat Pump Cooling Capacity	Estimated Annual Electric Savings	Estimated Annual Fossil Fuel Savings	Estimated Annual Energy Cost Savings	Opinion of Probable Cost
	tons	*tons*	*kWh*	*therms*	*$*	*$*
Heat Pump Water Heater, High School	--	--	-26,439	3,805	$465	$63,100
Percent of Baseline Usage - Heat Pump Water Heater			*-2%*	*3%*		

OVERVIEW

As summarized above, DHW is provided to the high school building by a natural gas fired DHW heater with an integral 125-gallon storage tank, which was installed around 2018. If the District is interested in full decarbonization at this time, there is an option to replace the existing gas-fired DHW heater with an air-source heat pump water heater with an integral storage tank. The water heater could be located in the mechanical room where the current water heater is located and tied into the existing infrastructure. Note that these systems work most efficiently when installed in a relatively warm room, such as a boiler room, because they absorb heat from the ambient air. Installing them in colder storage rooms could cause them to run less efficiently.

The table above does not include the energy savings and costs related to replacing the electric resistance DHW heater in the administration building. Heat pump water heaters may have coefficients of performance (COPs) of up to 4, compared to the max COP of 1 for an electric water heater. Therefore, a heat pump water heater could use a fraction of the electricity used by an electric resistance water heater. However, the energy and emissions savings of replacing the existing DHW heater with an air-source DHW heater would likely be very small relative to the cost of installation. Due to the condition of the existing water heater and the fact that it does not currently use fossil fuels, we assumed the existing water heater would be retained until it reaches its end of its useful life. At that time, the school district may wish to consider replacement with an air-source heat pump water heater.

OPINION OF PROBABLE CONSTRUCTION COST

Table 18: High School DHW Heat Pump Opinion of Probable Construction Budget Cost.

Category	Estimated Budget
HVAC Equipment	$10,000
HVAC Piping, Ductwork, Other Materials	$8,000
HVAC Installation	$2,800
Electrical Branch Circuit Materials and Labor[1]	$7,100
Startup, Commissioning, TAB, Closeout	$2,800
Controls	$0
Engineering	$6,100
Contractor General Conditions & PM Labor	$18,400
Contractor Overhead & Profit	$3,700
Contingency	$4,200
Grand Total	**$63,100**

[1] Budget assumes no change in main electrical service and distribution. Further engineering needed to confirm and/or estimate costs

Given the volatile nature of construction costs in the current market, we recommend that the above estimates be considered preliminary budgets for purposes of vetting whether this building is a good candidate to proceed to the next phase of the process. In general, projects with a full set of design drawings and specifications are expected to have actual contractor bids within +/- 10 – 15% of a third-party cost estimator's projection. In this case, where the proposed system has not been designed, actual costs could vary by a much wider margin and the final design scope is likely to change and be refined as further investigation and coordination are completed in subsequent design phases.

ELECTRICAL INFRASTRUCTURE

Table 19: Electrical Infrastructure Review Summary

Existing Conditions			Calculated Additional Peak Load				
Rated Capacity	Estimated Peak Demand	Available Spare Capacity	Air-to-Air Heat Pumps			Central Air-to-Water Heat Pump	DHW Heat Pump
			High School	WWTP	Admin	High School	High School
A	*A*	*A*	*A*	*A*	*A*	*A*	*A*
2,000	581	1,419	942	66	43	904	67

As part of this study, B2Q performed a high-level preliminary review of the main electrical service and equipment. The existing main switchboard is rated for 2,000A at 480V, 3-phase power. Peak demand data from utility bills indicate that the peak demand between January 2020 and May 2023 is 425 kW, which equates to approximately 581A. Note these values include an additional 25% of the metered peak demand in alignment with National Electric Code (NEC) requirements specified in section 220.87. Also, note that the metered peak demand represents the combined peak demand of the high school, administration building, and WWTP.

The WWTP is fed from the main switchboard in the high school. The main distribution panel in the WWTP is rated for 400A at 480V, 3-phase power. The administration building is fed from the main distribution panel in the WWTP. The main distribution panel in the administration building is rated for 150A at 480V, 3-phase power. At the time of this study, sub-metered electric demand data was not available for the WWTP or administration building main distribution panels.

With approximately 1,419A of spare capacity, the electrical infrastructure may be able to support Option 1 or Option 2 without a service upgrade. See the table above for high-level estimates of the additional loads related to the heat pumps in Option 1, Option 2, and DHW heat pumps. Modifications are likely required downstream of the main switchboard, though a more detailed study or design is required to enumerate and quantify the impact of this scope.

This review should be considered very preliminary given the limited, high-level scope of this study. Temporary metering should be included in the scope of a follow-on feasibility/design effort per the requirements of the National Electric Code (NEC), as it will ultimately be required for any electrification option. This should involve a licensed professional electrical engineer to more thoroughly evaluate the available capacity and ability of the existing systems to accommodate the increased electrical loads.

ENERGY CONSERVATION MEASURES

The following energy conservation measures (ECM) were also identified in this scoping study. Please note that the baseline of each ECM is the existing equipment operations and therefore the effects of the above proposed heat pump measures are not factored into the scope of the ECMs. As mentioned above, several of the ECMs are pre-requisites for significant heat pump upgrades, such as a new BAS. It should also be noted that the District's February 2023 Capital Plan includes replacing most major HVAC equipment, including the boilers, pumps, RTUs, AHUs, HVs, UVs, and EFs in the next 4 – 8 years, as much of the equipment has reached or is approaching the end of its useful life. Accordingly, some of the ECMs presented below, such as EC motor retrofits and re-commissioning, may already be included in the scope of the anticipated capital improvement projects or may not be recommended if the equipment will soon be replaced anyway.

Accordingly, we recommend the District and National Grid review the following information to assess which ECMs they are interested in pursuing further and then a follow up study can be performed to evaluate the interactive effects of all measures and capital improvement projects contemplated for implementation so that the District can be understand the expected net impact on the building.

The following measures provide a high-level view of the potential energy savings and costs and are not reflective of what would be produced by a detailed investment grade conceptual design and economic feasibility analysis. Energy savings were calculated using high-level estimates, past experience, and typical industry metrics.

ECM-1: LED LIGHTING UPGRADES AND CONTROLS

Table 20: ECM-1 Summary.

	ECM Description	Electricity Savings	Natural Gas Savings	Energy Cost Savings	Typical Payback			Extrapolated Project Cost Range		
-	-	kWh	therms	$	yr		yr	$		$
1	LED Lighting Upgrades & Lighting Controls	120,921	0	$19,799	3	-	6	$59,396	-	$118,793

While some interior lighting was retrofitted with LEDs from 2013 to 2015, most of the interior lighting is a combination of fluorescent T8s, CFLs, metal halides, and halogens. The lights are typically controlled by manual wall switches. Some classrooms were upgraded with occupancy sensors, however, many of them have been overridden, based on conversations with facilities staff.

In 2013, (90) parking lot pole lights were upgraded to LEDs; however, these lights have had some issues and were burning out prematurely. The District has since replaced 20-30 of the original LEDs with more modern LEDs. About a third of the building wall packs have also been upgraded to LEDs. The remaining exterior lights are metal halides with the exception of the field #2 flood lights which are halogen bulbs. The majority of exterior lighting is controlled through photocells and timeclocks. The field #2 lights are controlled through manual switches during sports practices and games.

It is recommended to implement a full LED retrofit for all remaining interior and exterior light fixtures. For each fixture replaced, the LED option typically provides anywhere from 50% to 80% power reduction, leading to significant electric demand and energy use savings throughout the year. Additional savings would also occur through reduced cooling load on the building HVAC systems (due to the lower wattage light fixtures), as well as reduced time and materials costs for upkeep of the LED systems, which have longer lifetimes than the existing fixtures.

Additionally, the following lighting controls could be considered for implementation:

- Integral occupancy sensors when replacing the T8s with new LED fixtures for corridors and stairs.
- Daylighting controls for the main stairwells and other rooms with large windows.
- Occupancy sensors for restrooms, breakrooms, and other support spaces.

ECM-2: Pneumatic to DDC Upgrades, New Building Automation System, and Re-Commissioning

Table 21: ECM-2 Summary.

	ECM Description	Electricity Savings	Natural Gas Savings	Energy Cost Savings	Typical Payback			Extrapolated Project Cost Range		
-	-	kWh	therms	$	yr		yr	$		$
2	Pneumatic to DDC Upgrades, New BAS, & Re-Commissioning	62,097	6,334	$18,143	8	-	15	$145,145	-	$272,148

The existing controls are a mix of pneumatic controls, direct digital controls (DDC), and standalone controls. The table below outlines the existing control systems found in the building and the equipment each system controls.

Control System	Equipment Controlled	Notes
Pneumatic Controls	- UVs, VAVs, and FTR with pneumatic thermostats in the classrooms - CUHs controlled via aquastats	- 90% of the building is pneumatic with limited E/P overlay. - (1) air compressor motor is broken, system only running on one
Johnson Controls (JCI) Metasys	See description for Facility Explorer	Obsolete system with no additional capacity for new controllers or equipment
MicroTech I	Older McQuay RTUs	Used to integrate McQuay RTUs with JCI system. Controller is obsolete and new equipment can no longer interface with it.
Facility Explorer	AHU-3, RTU-10, 11, and 12, HV-1 through 8	Enables web-based graphical user interface for some equipment
Heat Timer	High School Boiler Plant	Standalone system with limited JCI integration.
Programmable Wi-Fi Honeywell thermostats	Administration air handler WWTP unit heaters	Standalone system with no JCI integration.

As a result of the age, reliability, and lack of visibility into the existing systems, the building operator is required to manually intervene and tune operations consistently through each day and season to achieve comfortable conditions for occupants. Some examples of the manual control to maintain the building operations include space temperature setpoints, hot water supply temperature setpoint, outside air damper positions, and VFD speeds.

This measure proposes replacing the existing pneumatic controls and upgrading the existing JCI Metasys system with a new modern building automation system (BAS). This would involve installing a new electronic controller for each major piece of HVAC equipment, such as the RTUs, AHUs and unit ventilators, as well as a supervisory controller to manage schedules, alarms, communication, and host the graphical user interface. New IT network wiring would be installed to connect the various controllers and new digital end devices, such as sensors, actuators, and relays, would be installed at each piece of HVAC equipment to read and control the inputs and outputs of the equipment. In addition, the following improved control strategies are recommended:

- **Equipment scheduling** (see ECM-3 for additional details and energy savings): There is limited scheduling for the existing equipment with some equipment running 24/7 during the school year.
- **Economizer control**: A glitch in the BAS controls has required the building engineer to override the outside air damper positions for all ventilation equipment. There is currently no economizer operation in the building. Implementing economizer control at the RTUs and AHU would improve tenant comfort and reduce the DX cooling load on the units with cooling.
- **Discharge Air Temperature (DAT) Reset**: The existing systems maintain a constant DAT setpoint. Resetting the DAT setpoint could increase the economizer hours and reduce the reheat required in the space.
- **Duct Static Pressure Reset**: The existing variable flow systems maintain a constant duct static pressure (DSP) setpoint. Resetting the DSP setpoint would allow the fans to ramp down when conditions allow.
- **Optimized heat and cooling lockout:** Implement heating and cooling lockout temperatures on the RTUs and AHU with both heating and cooling to avoid simultaneously heating up and cooling down the supply air.
- **HW Supply Temperature Reset:** The building operator manually sets the HW supply temperature based on the outside air temperature. He maintains 150°F during milder weather and 180°F in cold conditions. Programming the HW supply temperature setpoint to automatically reset the setpoint based on the outside air conditions could result in natural gas savings.

This measure is expected to result in energy savings driven by more precise control of valve and damper actuators, as well as enabling improved sequences of operation and unoccupied setbacks. While many of these strategies are employed to a limited degree by the facilities staff manually through the E-P controls, full DDC upgrades would signify a noticeable improvement in control functionality and visibility. Upgrading zone level pneumatic equipment to DDC is also expected to improve occupant comfort and equipment maintainability.

As part of the BAS upgrade, B2Q recommends including a recommissioning (RCx) scope. Due to the lack of visibility into the existing systems operations, it is likely there are some failed end devices, such as fan motors, hot water valves, or unit ventilator dampers, that have gone unnoticed. Once the new BAS is in place and operators have direct visibility into the equipment's operations, a process of testing and monitoring each piece of equipment could help uncover these issues and allow them to be corrected by the BAS contractor while they are mobilized so that the controls system is turned over to the District in full working order.

ECM-3 & 4: Exhaust Fan and Unit Ventilator Scheduling

Table 22: ECM-3 & 4 Summary.

ECM Description	Electricity Savings	Natural Gas Savings	Energy Cost Savings	Typical Payback	Extrapolated Project Cost Range
- -	kWh	therms	$	yr yr	$ $
3 Exhaust Fan Scheduling	188,181	0	$30,812	1 - 3	$30,812 - $92,435
4 Unit Ventilator Scheduling	107,413	2,061	$20,182	1 - 3	$20,182 - $60,546

There is limited equipment scheduling for a number of systems in the building, including:

- **Exhaust fans**: There are (37) exhaust fans in the high school, most of which run 24/7 year-round.
- **Unit Ventilators**: Due to issues with BAS, the unit ventilator schedule reportedly does not work. The UVs are manually shut off in the summer and run 24/7 during the school year to maintain their thermostat's single setpoint.

Following a BAS upgrade, this measure implementing a schedule to follow the school's occupied hours for all HVAC equipment.

ECM-5 & 6: Exhaust Fan and Unit Ventilator EC Motor Retrofits

Table 23: ECM-5 & 6 Summary.

ECM Description	Electricity Savings	Natural Gas Savings	Energy Cost Savings	Typical Payback	Extrapolated Project Cost Range
- -	kWh	therms	$	yr yr	$ $
5 Exhaust Fan EC Motor Retrofits	23,658	0	$3,874	10 - 15	$38,736 - $58,104
6 Unit Ventilator EC Motor Retrofits	54,632	0	$8,945	10 - 15	$89,451 - $134,176

Each of the estimated (60) unit ventilators and (37) exhaust fans serving the high school are currently driven by a permanent split core (PSC) motor. An alternative technology would be to use electronically-commutated (EC) motors. EC motors are inherently more efficient than PSC motors because they utilize direct current (DC) power and do not feature brushes to control polarity. The difference in efficiency between the two motor types is most significant in small motor sizes (i.e., less than 3 hp) when PSC motors are generally much less efficient than they would be in larger sizes (i.e., greater than 10 hp). As such, small fan applications such as unit ventilators, exhaust fans, fan-powered boxes, unit heaters, etc. are generally the best candidates for this kind of retrofit. This measure would propose to make a direct motor replacement without changing the existing fans. Careful coordination in motor selection is necessary and, in some cases, retrofit kits with mounting brackets are required to help EC motors with slightly different physical dimensions than their PSC analogs fit into the existing equipment. If any of the existing fans or unit ventilators themselves are in poor enough condition that they warrant full replacement, then it is possible to furnish new equipment with integral EC motors from the factory, though typically at a greater cost than estimated in the cost estimate provided in this report for this measure.

ECM-7: Motor Retrofits for VFDs

Table 24: ECM-7 Summary.

ECM Description	Electricity Savings	Natural Gas Savings	Energy Cost Savings	Typical Payback	Extrapolated Project Cost Range
- -	kWh	therms	$	yr - yr	$ - $
7 Motor Retrofits for VFDs	51,192	0	$8,382	2 - 4	$16,764 - $33,527

Based on conversations with facilities staff, many, if not all, of the existing AHU/RTU supply and return fans have been retrofitted with variable frequency drives (VFDs). However, the fan motors were not replaced and are not compatible for use with VFDs, and therefore, the VFDs have been disconnected and the fans run at constant volume. This measure proposes motor replacements which are compatible with the existing VFDs. Controls programming would be implemented for variable volume control to maintain duct static pressure or space temperature.

Capital Improvement Measures

The District's capital plan includes several HVAC equipment replacement projects, which present the opportunity to replace existing equipment with high-efficiency equipment to reduce energy use while also improving equipment operability and maintainability. Energy savings were not calculated for these measures, but potential opportunities for high-efficiency replacements are noted below.

RTU Replacements

The (4) existing roof top units (RTU) that serve the high school and WWTP are 23 years old, inefficient, beyond their useful life, and failing. Below is a sample of the issues with these systems:

- RTU-10 recently caught fire
- RTU-12 DX cooling is failed and the VFD is broken

This capital improvement measure includes replacing the units with high-efficiency DX cooling (as applicable), natural gas heating units. While many of the existing RTUs have HW coils, reusing the exiting HW piping may not be preferred, as there are concerns that the existing HW piping infrastructure is beyond its useful life. Also, bringing HW to the roof without proper glycol maintenance poses a reliability and maintenance concern. There is the potential for the HW piping and coils in the RTUs to freeze resulting in significant damage to the unit and potentially the building. As part of the RTU replacement, the points for the new units should be integrated with the new BAS for full visibility and control. The new units could be programmed with the controls optimization recommendations noted above in ECM-2. The new RTUs should also include code required outside air control, 100% economizer capability, high-efficiency DX cooling, and a heating efficiency of 80% or greater.

For packaged heat pump RTU replacement options, see Option 1B in the electrification section above.

Condensing Unit Replacements

The (1) existing air cooled condensing unit (ACCU) serving the DX cooling coil in AHU-3 is 23 years old, inefficient, beyond its useful life, and failing. More specifically, ACCU-3 only has a single stage of cooling, and its control board is obsolete.

This capital improvement measure recommends replacing the unit with a high-efficiency ACCU with staging control. As part of the ACCU replacement, the points for the new unit should be integrated with the new BAS for full visibility and control.

For heat pump replacement options, see Option 1A in the electrification section above.

Boiler Replacements

The (2) existing 4,640 MBH output Weil-McLein boilers are original to the building and are past the end of their useful lives. While heat pump retrofits would be the preferred means of providing the building with a new heating system that aligns with the Commonwealth's legislative and policy goals for decarbonization, in the short term it may be desirable to the District to implement a lower cost project to replace the existing gas-fired boilers with new higher efficiency gas-fired condensing boilers to keep the building operational while other maintenance and efficiency projects are prioritized in the district. Newer boilers could be provided with energy efficient features, such as automatic dynamic combustion controls and exhaust heat recovery that can yield significant savings relative to existing operations if this option is pursued. Further, new gas-fired condensing boilers could be used as a supplemental and/or backup heating source for the air-to-water heat pump described in Option 2 in the electrification section above.

Other Potential Measures

The following measures were identified during our site walkthrough and/or in the District's capital plan, but not considered in detail. While many of these measures have small energy savings associated with them, the primary drivers are maintenance requirements, tenant comfort, reliability, and health and safety. Energy savings were not calculated for these measures at this time.

Roof Replacement

The existing roof is an adhered, black EPDM roof that is 28 years old. The existing level of insulation is unknown. There are numerous patches and soft spots throughout the roof and the maintenance staff indicated there are a few leaks when it rains. The roof is beyond its useful life and in need of replacement. In addition, the leaks and soft spots indicated a potential reduction in the current insulation's effectiveness.

Should the roof be replaced, this presents an opportunity to re-establish a continuous air/vapor barrier (AVB) and add additional insulation. An air/vapor barrier is needed in the roof assembly to prevent migration of interior air into the roof assembly where it might condense and lead to an accumulation of moisture.

WEATHERIZATION IMPROVEMENTS

B2Q observed several exterior doors with missing or damaged weather stripping. Installation of new weather stripping could improve occupant comfort and reduce heating energy use.

B2Q suggests that the District consider hiring a weatherization specialist to compete a building envelope assessment of the school to identify additional opportunities, such as air sealing and insulation improvements, as well as to quantify the energy savings potential. Note that pairing weatherization improvements with heat pump retrofit projects may be required as a corequisite for certain grants/incentives.

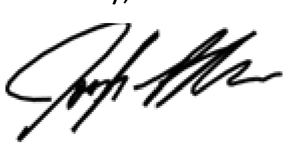
Recommended Next Steps

In summary, further planning and detailed engineering review are necessary in preparation for the next phases of design and construction of energy conservation measures and/or electrification options. Here are the recommended next steps:

- Internal review to be completed by Masconomet Regional School District to determine if interested in pursuing energy conservation measures and/or electrification at these buildings further and assess how they interact with the existing capital plan for HVAC equipment replacements and controls upgrades. Please make B2Q aware of any errors or omissions that may have impacted our results or recommendations. We would be glad to issue an updated report that addresses any such concerns.
- Meet with B2Q and National Grid representatives to discuss any questions about the information contained in this report, including these Next Steps.
- Coordinate with representatives from National Grid to obtain an estimate of potential utility incentives for the ECMs and electrification options.
- Assess which options outlined in this report are of greatest interest for further investigation. Note that, as discussed above, the factors that influence the choice of one option over another include a multitude of factors, such as estimated construction cost, compatibility with the existing building and equipment, impact on annual energy/operating costs, reliability/resiliency, ability to operate and maintain the equipment, etc. so the District should consider its own goals and priorities in relation to these projects as part of the decision-making process.
- Consider working with stakeholders to secure funding for a follow up effort to conduct a more detailed feasibility study and/or schematic design to better develop the scope of work and obtain a third-party cost estimate to inform capital planning.
- Consider utilizing available funding and/or applying for funding from the Commonwealth, utilities, and/or Federal programs to proceed toward implementation of any ECMs that are of interest and would be compatible with the District's preferred electrification option, if any.

We would be happy to meet with you to discuss any questions or comments you have on the above information. Thank you for the opportunity to work with you on this effort.

Sincerely,



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