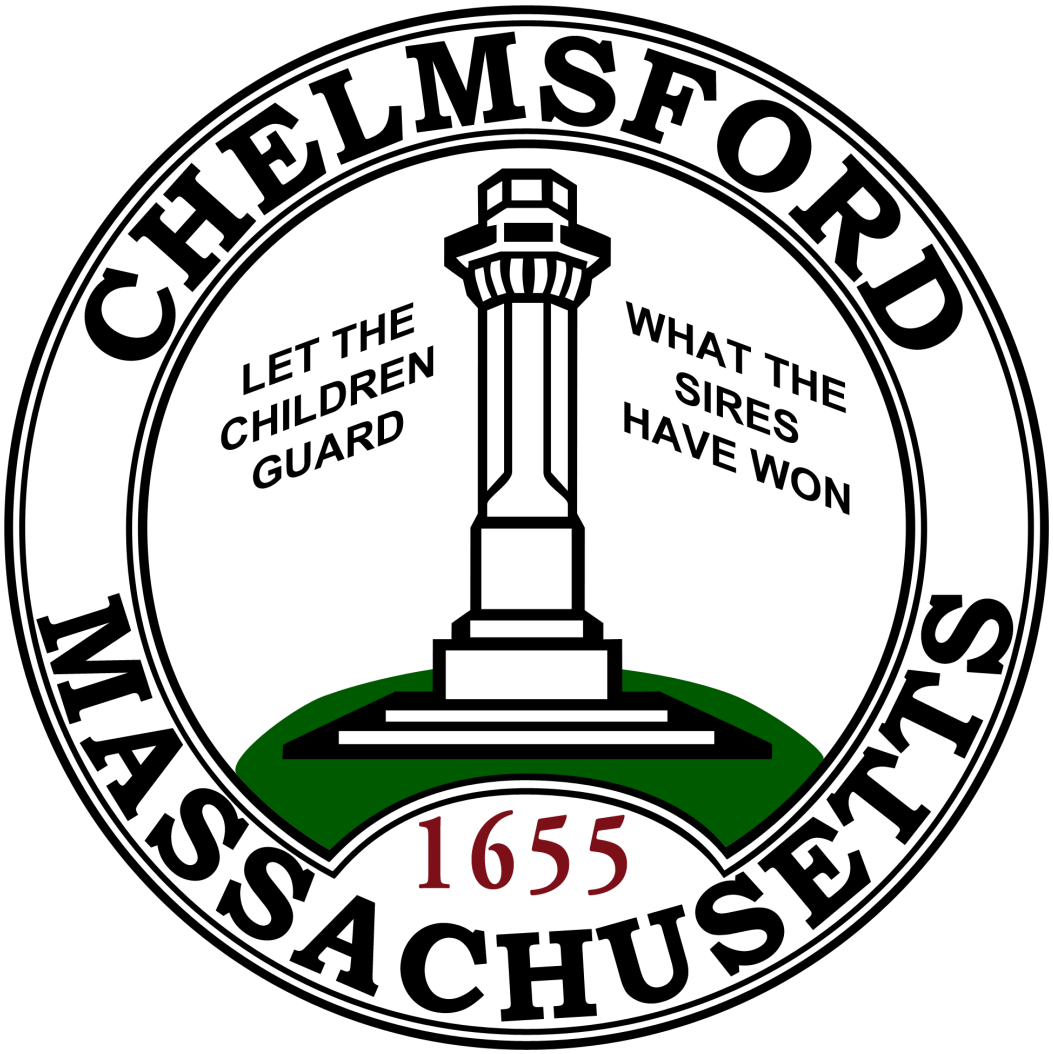
ENHUEX

Where human experience soars

FINAL REPORT:

Chelmsford Public School Building Electrification Roadmap Study



Town of Chelmsford

The Town of Chelmsford, Massachusetts, is a vibrant community dedicated to sustainability and climate action. As a designated Green Community, Chelmsford actively pursues energy conservation initiatives, including efficiency upgrades, renewable energy projects, and emissions reduction strategies. Committed to achieving carbon neutrality by 2050, the town implements policies aligned with Massachusetts' decarbonization goals, fostering a cleaner, more sustainable future for its residents.

Chelmsford Committee

The development of this Electrification Roadmap was made possible through the collaboration of the Department of Public Works (DPW) Facilities Group and School Central Administration. Their expertise in the town's infrastructure, energy systems, and operational needs was instrumental in shaping this strategic plan. Their contributions ensure the roadmap is technically robust and aligned with Chelmsford's long-term sustainability goals for its public schools and municipal facilities.

ENHUEX LLC

The project consultant, ENHUEX LLC, is a technology development and consulting firm specializing in innovative decision-support solutions at the nexus of human, machine, and societal systems. With deep technical expertise in energy efficiency, system optimization, and advanced analytics, ENHUEX delivers high-impact strategies for public, government and private sector clients. From optimizing urban transportation networks to guiding municipal decarbonization efforts, ENHUEX leverages cutting-edge system-level thinking to drive measurable outcomes. Our collaborative approach, grounded in technical rigor and practical insights, empowers communities like Chelmsford to achieve ambitious sustainability goals while balancing financial and operational priorities.

Disclaimer

The information, analysis, and findings in this report are provided by ENHUEX LLC as part of an independent, high-level study commissioned by the Town of Chelmsford. These estimates and recommendations are intended solely for strategic planning purposes to support the town's sustainability objectives. They are based on preliminary assessments, industry standards, and available data, not detailed engineering designs, comprehensive theoretical models, or exhaustive empirical analysis. Actual costs, timelines, and outcomes may vary significantly due to site-specific conditions, technological advancements, market fluctuations, or other factors. ENHUEX LLC assumes no liability for decisions or actions taken based on this report, and users are advised to conduct detailed engineering and financial analyses before implementing any recommendations.

Table of Contents

Executive Summary

The Town of Chelmsford, a designated Green Community committed to carbon neutrality by 2050, commissioned this Electrification Roadmap Study to evaluate transitioning nine public school buildings to electrified HVAC systems. Conducted by ENHUEX LLC, this study provides a strategic decision-support framework to advance the town's sustainability goals, aligning with Massachusetts' net-zero emissions target. The analysis compares a Business-as-Usual (BAU) scenario, maintaining fossil fuel-based HVAC systems, with an Electrified scenario. Through a high-level 28-year Life Cycle Cost Analysis (LCCA), it estimates costs, energy impacts, and Greenhouse Gas (GHG) reductions, offering a foundation for informed planning.

Table ES summarizes the recommended electrification timeline and financial metrics for each facility. The timeline, spanning 2028 to 2046, is based on the remaining useful life of existing equipment to maximize current investments. Costs are high-level estimates, requiring detailed engineering assessments to refine, particularly for aging buildings. Utility-side upgrades and potential incentives are excluded, which could significantly affect final costs.

Table ES - Electrification Timeline and Cost Comparison

Year	Facility	Capital Investment (2024 $)			Life Cycle Costs (2024 $)		
		Electrification	BAU	Delta	Electrification	BAU	Delta
2028	Parker Middle School	$6,117,550	$1,050,000	$5,067,550	$12,571,861	$4,721,007	$7,850,854
2036	South Row Elementary	$3,640,359	$592,070	$3,048,289	$6,256,313	$3,107,519	$3,148,794
2037	Central Admin	$756,278	$101,920	$654,358	$1,635,697	$1,024,068	$611,629
2042	Byam Elementary	$3,002,188	$675,360	$2,326,828	$5,071,368	$2,535,514	$2,535,854
2043	Chelmsford High	$16,641,244	$2,858,820	$13,782,424	$29,206,080	$15,867,603	$13,338,477
	Center Elementary	$3,036,929	$495,950	$2,540,979	$5,543,681	$3,130,135	$2,413,546
2044	Community Education	$1,709,700	$371,000	$1,338,700	$3,710,780	$1,740,928	$1,969,852
	Harrington Elementary	$4,015,559	$675,360	$3,340,199	$6,721,493	$2,837,919	$3,883,574
2046	McCarthy Middle	$8,515,938	$1,440,000	$7,075,938	$14,104,930	$6,443,134	$7,661,797
TOTAL		**$47,435,744**	**$8,260,480**	**$39,175,264**	**$84,822,204**	**$41,407,827**	**$43,414,377**

The LCCA indicates the Electrified scenario costs $84.8 million over 28 years, compared to $41.4 million for BAU, driven by high upfront capital costs. As shown in Section 7.1, while the Electrified scenario eliminates natural gas costs, saving $2.5 million, and reduces maintenance expenses by $3.7 million, the electricity usage costs are increased from $10.4 million to $20.8 million over the life cycle. GHG emissions are significantly reduced, as shown in Section 6.4, supporting decarbonization goals. This roadmap underscores Chelmsford's commitment to a sustainable future, balancing environmental objectives with financial considerations.

Table of Acronyms and Abbreviations

Abbreviation	Description
AHU	Air Handling Unit
ASHP	Air Source Heat Pump
BAU	Business-as-Usual
BTU	British Thermal Unit
CMU	Concrete Masonry Unit
DDC	Direct Digital Control
DHW	Domestic Hot Water
DOE	U.S. Department of Energy
DPW	Department of Public Works
DX	Direct Expansion
ECM	Energy Conservation Measure
ESPC	Energy Savings Performance Contract
GHG	Greenhouse Gases
GSHP	Ground Source Heat Pump
HTHW	High-Temperature Hot Water
HVAC	Heating, Ventilation, and Air Conditioning
kWh	Kilowatt-Hour
LCCA	Life Cycle Cost Analysis
LTHW	Low-Temperature Hot Water
MBH	Thousand British Thermal Units per Hour
MBTU	Thousand British Thermal Units (10^3 BTU)
MT CO2e	Metric Ton Carbon Dioxide Equivalent
PTAC	Packaged Terminal Air Conditioner
PV	Photovoltaic
RTU	Rooftop Unit
The Town	The Town of Chelmsford
VRF	Variable Refrigerant Flow

1. Introduction

In alignment with Massachusetts' commitment to achieving net-zero greenhouse gas emissions by 2050, the Town of Chelmsford is proactively implementing energy conservation and efficiency measures to eliminate carbon emissions within the same timeframe. A key component of this initiative is the electrification of the town's nine public school buildings, transitioning them from fossil fuel-based systems to energy-efficient, electrified operations. This effort is supported by the town's Energy Savings Performance Contract (ESPC) with Johnson Controls, initiated in 2013, which includes 26 energy conservation measures across municipal facilities. Additionally, under the Massachusetts Green Communities Act, Chelmsford developed a Climate Leaders Roadmap in 2024, guiding the elimination of fossil fuel use in municipal buildings and vehicles.

This report presents a study to identify electrification strategies, focusing on high-level cost analysis to compare Business-as-Usual (BAU) scenarios with electrified alternatives. The primary objective is to provide Chelmsford's decision-makers with clear insights into the financial implications of electrifying all nine school buildings, supporting informed planning for electrified school infrastructure.

Table 1 - Chelmsford Public School Buildings Considered in This Study

Building	Address	Area (Sq. Ft.)	Year Built
Chelmsford High School	200 Richardson Rd, North Chelmsford, MA 01863	285,882	1974
Byam Elementary School	25 Maple Rd, Chelmsford, MA 01824	67,536	1970
Chelmsford Community Education	170 Dalton Rd, Chelmsford, MA 01824	37,100	1968
Harrington Elementary School	120 Richardson Rd, North Chelmsford, MA 01863	67,536	1967
McCarthy Middle School	250 North Road, Chelmsford, MA 01824	144,000	1959
Parker Middle School	75 Graniteville Rd, Chelmsford, MA 01824	105,000	1965
Center Elementary School	84 Billerica Rd, Chelmsford, MA 01824	49,595	1955
South Row Elementary School	250 Boston Rd, Chelmsford, MA 01824	59,207	1963
Central Administration Building	230 North Road, Chelmsford, MA 01824	10,192	1968

Serving as a high-level decision-support tool, this study offers strategic insights consistent with the independent analysis commissioned by ENHUEX LLC. The findings are designed to equip the Town of Chelmsford with the information needed to develop overarching strategies and pursue progressive actions toward its sustainability goals. The analysis is based on preliminary assessments, not detailed engineering designs or exhaustive empirical studies, as noted in Section 6.5.

2. Building System Inventory

This section provides an overview of the mechanical, electrical, and plumbing systems across the nine public school facilities in this electrification study, forming the baseline for electrification strategies. This inventory was developed by reviewing Town of Chelmsford documentation, engaging stakeholders, and conducting site surveys as needed. Minor school growth is expected but deemed insignificant for this study.

2.1 Chelmsford High School

Building Overview. Built in 1974, this facility has 285,882 sq. ft. of conditioned space. Recent upgrades include new boilers in 2023 and kitchen renovations in 2024. It features classrooms, labs, a performing arts center, and athletic facilities.

Existing Building Systems. Five gas-fired condensing boilers, installed in 2023, provide heating. Cooling is supplied through rooftop units with direct expansion (DX) coils and split systems serving select areas. The electrical system retains its original 1974 switchgear, including a 3,000-amp, 277/480V, 3-phase, 4-wire switchboard. A roof-mounted photovoltaic (PV) system supports energy generation. Plumbing includes a gas-fired water heater. An emergency generator, serviced in 2023, is in good condition.

2.2 Byam Elementary School

Building Overview. Built in 1970, this two-story facility has 67,536 sq. ft. of conditioned space. Upgrades include window replacements in 2004 and a roof replacement in 2011.

Existing Building Systems. Three gas-fired boilers, installed in 2022, provide heating with ceiling-suspended unit ventilators from 2014. Cooling is limited to administrative offices using packaged terminal air conditioners (PTACs) and a technology classroom with a ductless split system. The electrical service comprises a 1,200-amp, 120/208V system fed from a pad-mounted transformer, with fluorescent and LED lighting. A roof-mounted PV system was installed in 2011. Plumbing features vitreous china and stainless steel fixtures, with a 100-gallon gas-fired water heater.

2.3 Chelmsford Community Education

Building Overview. Built in 1968, this two-story facility has 37,100 sq. ft. of conditioned space, serving community education, after-school programs, and summer school.

Existing Building Systems. Two gas-fired boilers, installed in 2024, replacing 2006 units, provide heating. Cooling is available through unit ventilators and split systems in select areas, with roof-mounted exhaust fans supporting ventilation. The electrical infrastructure includes a 1,200-amp main service with branch circuit panelboards. A roof-mounted PV system supports energy generation. Domestic hot water (DHW) is supplied by two 100-gallon gas-fired water heaters.

2.4 Harrington Elementary School

Building Overview. Built in 1967, this two-story facility has 67,536 sq. ft. of conditioned space, sharing a campus with Chelmsford High School. Upgrades include new boilers in 2024, windows in 2004, and a roof in 2011.

Existing Building Systems. Three gas-fired boilers, installed in 2024, replacing 2002 units, distribute heat through unit ventilators (2013), fin-tube radiators, and convectors, many nearing end-of-life. PTACs and split systems cool administrative offices, a technology classroom, and select spaces. The electrical service is a 1,200-amp, 120/208V system from a utility-owned pad-mounted transformer, with mixed panelboards. A roof-mounted PV system supports energy generation. Plumbing includes manual vitreous china fixtures and two gas-fired water heaters for domestic hot water.

2.5 McCarthy Middle School

Building Overview. Built in 1959, this two-story facility has 144,000 sq. ft. of conditioned space, classified as Type II-A/II-B construction with a concrete-framed structure and load-bearing walls. Upgrades include mechanical systems and fire alarms, but it lacks comprehensive fire suppression.

Existing Building Systems. Four gas-fired boilers, installed in 2006, with 2,000 thousand British thermal units per hour (MBH) input capacity, distribute heat through hot water pumps, baseboard radiation, and unit ventilators. Cooling is limited to ductless heat pumps in administrative areas, a rooftop unit in the library, and unit ventilators with economizer cooling in classrooms; the gymnasium and auditorium are uncooled. The electrical system includes a 2,000-amp, 120/208V, 3-phase switchboard with outdated panelboards. Switchgear renovation is planned for 2025, and boilers are scheduled for replacement in 2025–2026. A roof-mounted PV system supports energy generation. Plumbing features water-conserving fixtures updated in 2015 and a gas-fired water heater.

2.6 Parker Middle School

Building Overview. Built in 1965, this three-story facility has 105,000 sq. ft. of conditioned space, classified as Type II-A/II-B construction with a concrete and masonry structure. Renovations in 2006 included technology, plumbing, lighting, and a library addition. It lacks comprehensive fire suppression.

Existing Building Systems. Four gas-fired boilers, installed in 2004, with 2,000 MBH input capacity, distribute heat through unit ventilators, baseboard radiation, and convectors. Cooling is limited to administrative areas, the library, and select classrooms using ductless split systems and rooftop units. The electrical service is an 800-amp, 277/480V system with mixed panelboards, including original Westinghouse units in poor condition and newer Cutler-Hammer replacements. A 65 kW natural gas generator provides emergency power. A roof-mounted PV system supports energy generation.

2.7 Center Elementary School

Building Overview. Built in 1955 and renovated in 1999, this single-story facility has 49,595 sq. ft. of conditioned space with a wood-framed structure and load-bearing walls. A fire suppression system was installed in 1999, with upgrades for accessibility and classrooms.

Existing Building Systems. Two gas-fired boilers, installed in 2023, distribute heat through hot water pumps, baseboard radiation, and unit ventilators. Cooling is provided by unit ventilators with chilled water coils (2014) serving classrooms and administrative areas. The electrical service is a 2,000-amp, 120/208V system with mixed panelboards. Lighting includes fluorescent fixtures with occupancy sensors in classrooms and LED in common areas. A roof-mounted PV system supports energy generation. Plumbing features copper piping, two gas-fired water heaters, and a fair-condition storm drainage system.

2.8 South Row Elementary School

Building Overview. Built in 1961, this single-story facility has 59,207 sq. ft. of conditioned space, classified as Type II-A/II-B construction with a steel frame and laminated beam structure. It lacks a fire suppression system.

Existing Building Systems. Two gas-fired cast iron steam boilers, rehabbed in 2016, distribute heat through unit ventilators, cabinet unit heaters, and finned radiation. Cooling is limited to the administration area and nurse's office using ductless heat pumps. The electrical system includes a 1,200-amp, 120/208V, 3-phase service with older panelboards in poor condition; a 400-amp service supports portable classrooms. A roof-mounted PV system supports energy generation. Plumbing features a gas-fired water heater and copper piping, lacking a master mixing valve. A direct digital control (DDC) system manages boilers, ventilators, and exhaust fans.

2.9 Central Administration Building

Building Overview. This single-story facility has 10,192 sq. ft. of conditioned space, serving as the administrative hub for Chelmsford Public Schools.

Existing Building Systems. A natural gas boiler, installed in 2017, provides heating. Cooling is provided by rooftop package units and mini-split heat pumps. No PV system is installed. Plumbing includes a gas-fired water heater for domestic hot water.

3. Business As Usual Case

This section establishes a baseline for comparing the costs and benefits of electrification options by forecasting energy consumption, utility costs, maintenance expenses, capital expenditures, and greenhouse gas (GHG) emissions. The forecast uses utility data from July 2022 to June 2024, excluding atypical consumption patterns from the COVID-19 pandemic, to analyze energy usage trends, price projections, and the long-term impacts of maintaining current systems.

3.1 Annual Utility Consumption and Costs

This subsection summarizes energy consumption and costs for each facility based on 2024 utility bills from the Town of Chelmsford. Natural gas costs average $0.78 per therm and electricity $0.21 per kilowatt-hour (kWh), derived from September–October 2024 bills across all nine facilities, excluding net metering credits. GHG emissions factors are 0.658 lb CO2e/kWh for electricity and 11.70 lb CO2e/therm for natural gas.

Thermal load profiles and annual usage estimates stem from monthly utility consumption averages between July 2022 and June 2024. These profiles provide insights into heating and cooling loads for the electrification roadmap. The methodology includes:

- Allocating 90% of natural gas usage to heating, ventilation, and air conditioning (HVAC) systems, accounting for other uses (e.g., kitchen equipment) and system inefficiencies.
- For electricity in schools with air conditioning, allocating 50% to HVAC, split seasonally: 100% for heating in winter (November–March), 100% for cooling in summer (June–August), and 50/50 in shoulder months (April–May, September–October).
- For schools without air conditioning, allocating 20% to HVAC for heating and ventilation: 100% for heating in winter, no cooling in summer, and 10% for ventilation in shoulder months.
- For domestic hot water (DHW), the average summer load during non-heating months was used as demand, with 80% efficiency for natural gas boilers.

These assumptions ensure consistency across all facilities.

3.1.1 Chelmsford High School

Annual heating and cooling load profile for Chelmsford High School is estimated based on utility usage as follows.

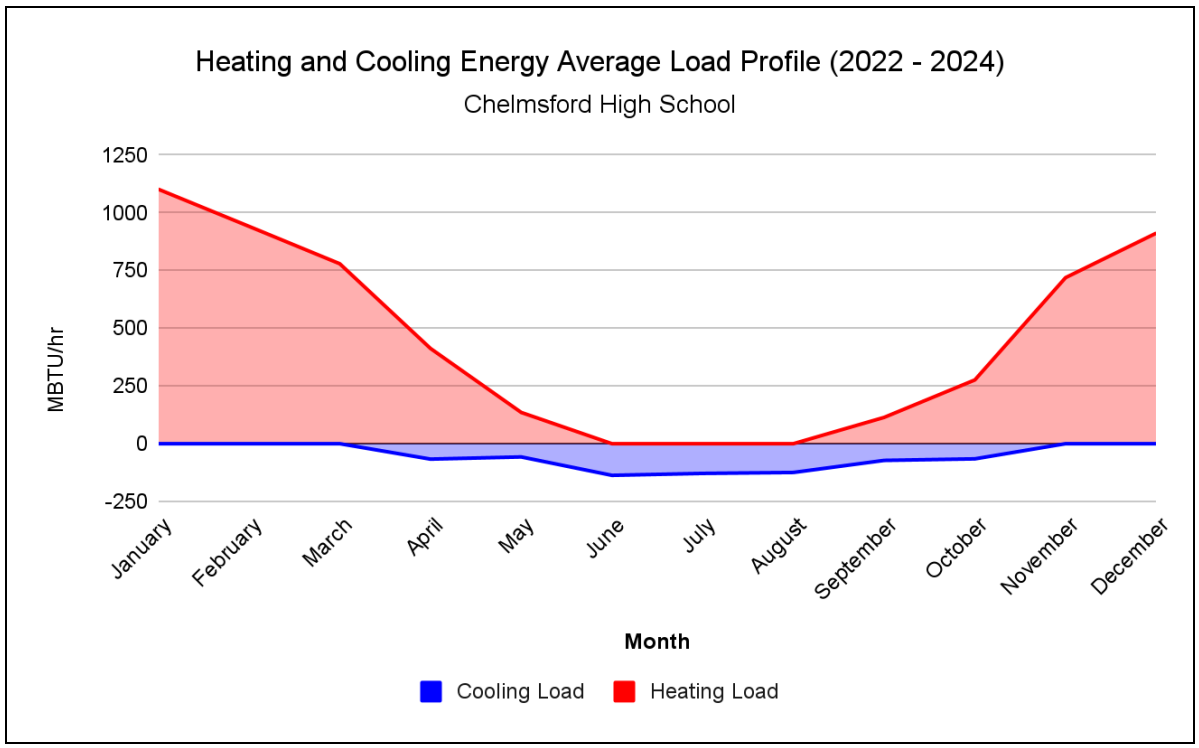


Figure 3.1.1 - BAU Case - Chelmsford High - Average Energy Load Profile

Table 3.1.1a - BAU Case - Chelmsford High School - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	921098
Natural Gas Heating (Therm/yr)	90308
TOTAL Heating/Cooling Energy (MBTU/yr)	12173695

Table 3.1.1b - BAU Case - Chelmsford High School - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$193,431
Natural Gas Heating Utility ($/yr)	$70,440
TOTAL Heating/Cooling Utility ($/yr)	$263,871

Table 3.1.1c - BAU Case - Chelmsford High - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	275
Natural Gas Heating (MTCO2e/yr)	479
TOTAL Heating/Cooling (MTCO2e/yr)	754

3.1.2 Byam Elementary School

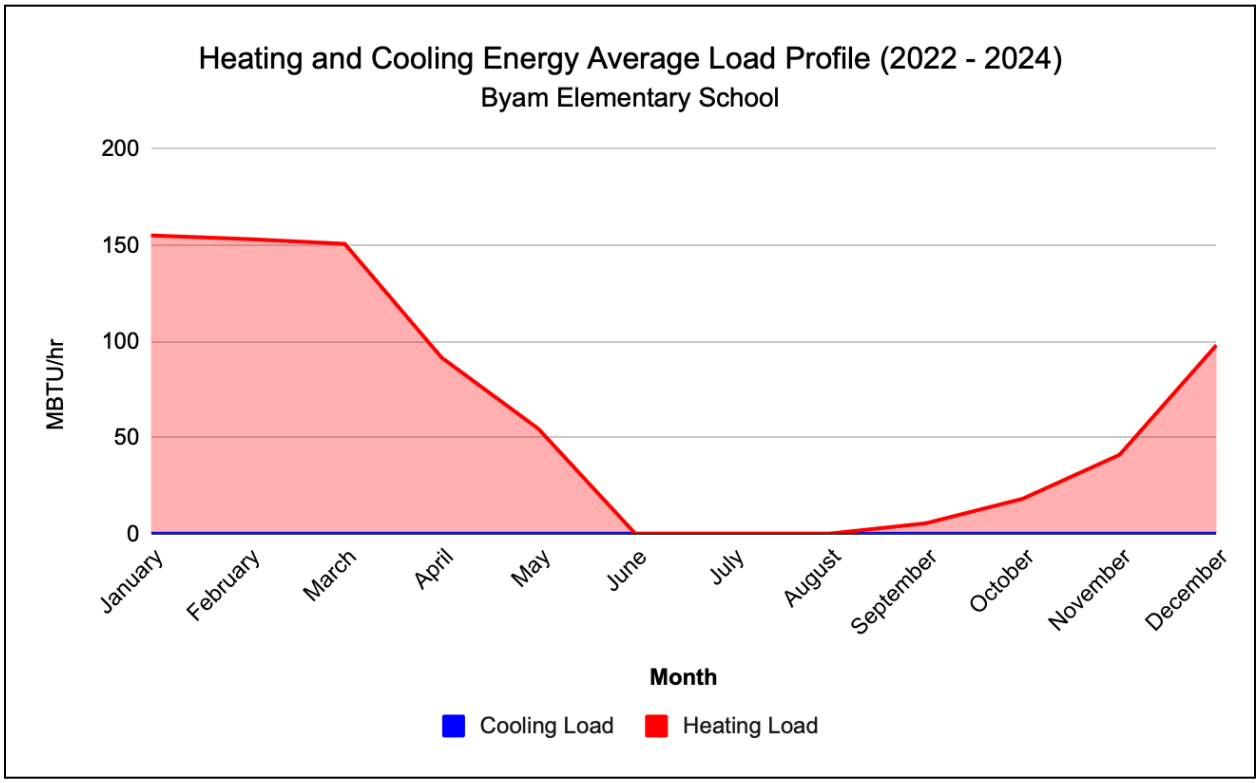


Figure 3.1.2 - BAU Case - Byam Elementary - Average Energy Load Profile

Table 3.1.2a - BAU Case - Byam Elementary - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	35551
Natural Gas Heating (Therm/yr)	14806
TOTAL Heating/Cooling Energy (MBTU/yr)	1601923

Table 3.1.2b - BAU Case - Byam Elementary - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$7,466
Natural Gas Heating Utility ($/yr)	$11,549
TOTAL Heating/Cooling Utility ($/yr)	$19,014

Table 3.1.2c - BAU Case - Byam Elementary - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	11
Natural Gas Heating (MTCO2e/yr)	79
TOTAL Heating/Cooling (MTCO2e/yr)	89

3.1.3 Chelmsford Community Education

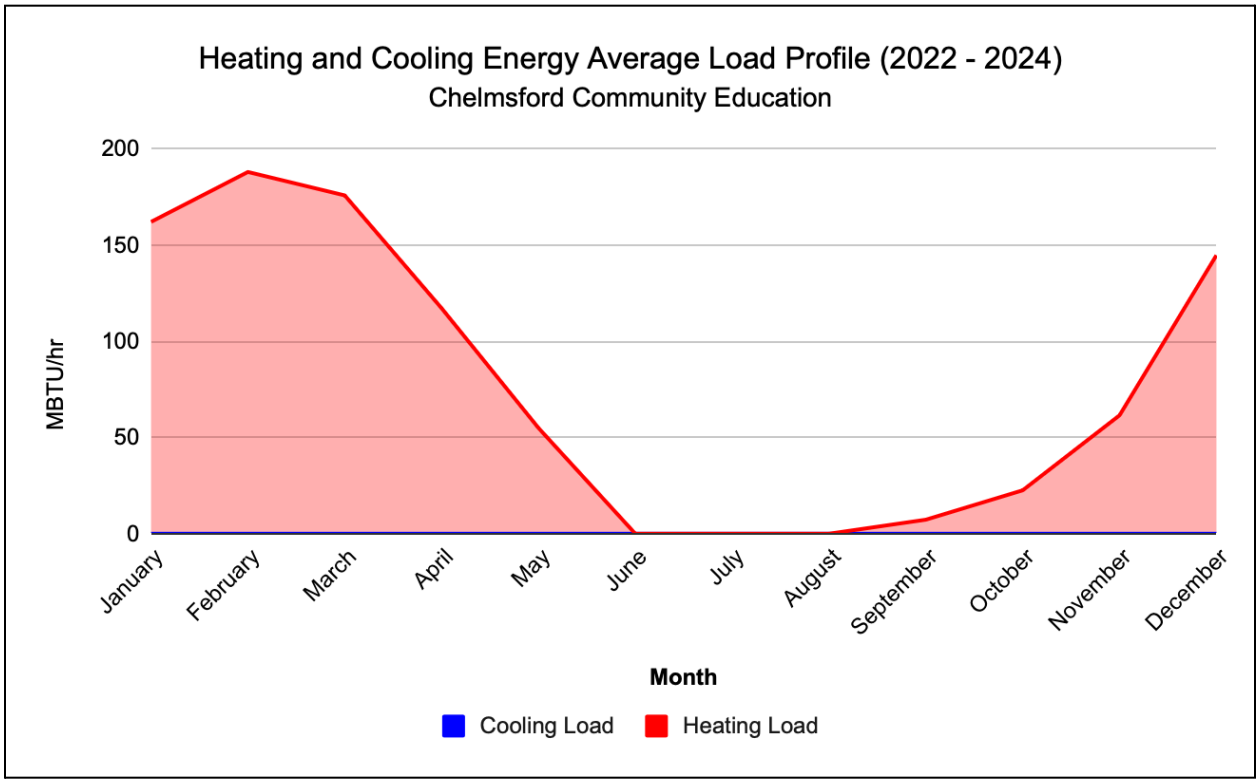


Figure 3.1.3 - BAU Case - Community Education - Average Energy Load Profile

Table 3.1.3a - BAU Case - Community Education - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	40786
Natural Gas Heating (Therm/yr)	18348
TOTAL Heating/Cooling Energy (MBTU/yr)	1973996

Table 3.1.3b - BAU Case - Community Education - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$8,565
Natural Gas Heating Utility ($/yr)	$14,312
TOTAL Heating/Cooling Utility ($/yr)	$22,877

Table 3.1.3c - BAU Case - Community Education - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	12
Natural Gas Heating (MTCO2e/yr)	97
TOTAL Heating/Cooling (MTCO2e/yr)	110

3.1.4 Harrington Elementary School

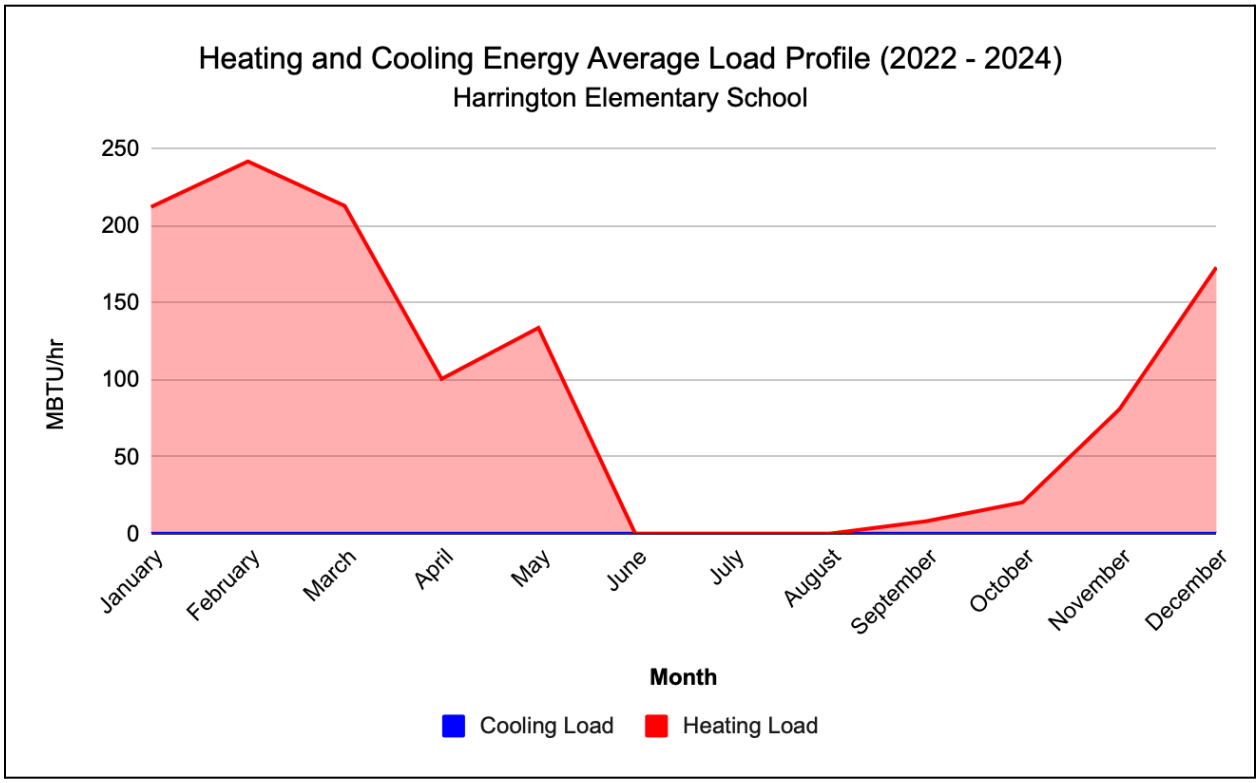


Figure 3.1.4 - BAU Case - Harrington Elementary - Average Energy Load Profile

Table 3.1.4a - BAU Case - Harrington Elementary - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	55861
Natural Gas Heating (Therm/yr)	23184
TOTAL Heating/Cooling Energy (MBTU/yr)	2509037

Table 3.1.4b - BAU Case - Harrington Elementary - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$11,731
Natural Gas Heating Utility ($/yr)	$18,084
TOTAL Heating/Cooling Utility ($/yr)	$29,815

Table 3.1.4c - BAU Case - Harrington Elementary - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	17
Natural Gas Heating (MTCO2e/yr)	123
TOTAL Heating/Cooling (MTCO2e/yr)	140

3.1.5 McCarthy Middle School

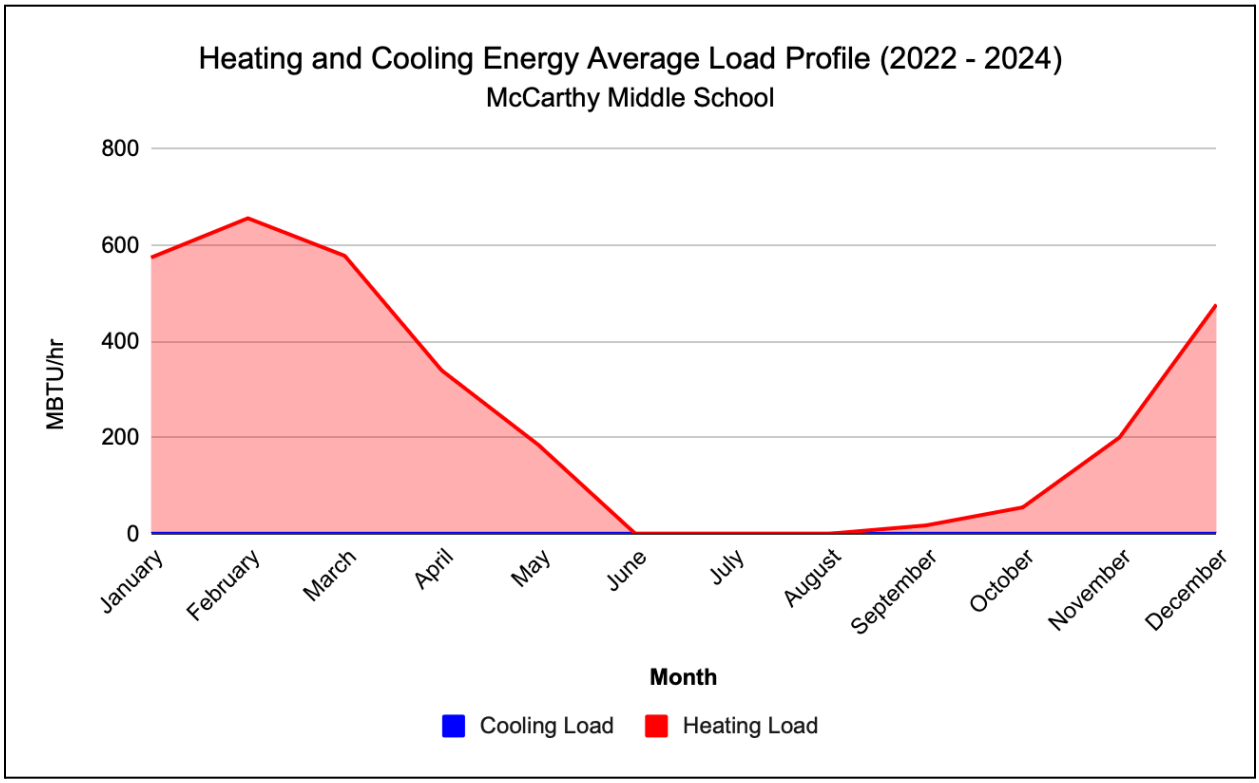


Figure 3.1.5 - BAU Case - McCarthy Middle - Average Energy Load Profile

Table 3.1.5a - BAU Case - McCarthy Middle - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	149605
Natural Gas Heating (Therm/yr)	59177
TOTAL Heating/Cooling Energy (MBTU/yr)	6428213

Table 3.1.5b - BAU Case - McCarthy Middle - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$31,417
Natural Gas Heating Utility ($/yr)	$46,158
TOTAL Heating/Cooling Utility ($/yr)	$77,575

Table 3.1.5c - BAU Case - McCarthy Middle - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	45
Natural Gas Heating (MTCO2e/yr)	314
TOTAL Heating/Cooling (MTCO2e/yr)	359

3.1.6 Parker Middle School

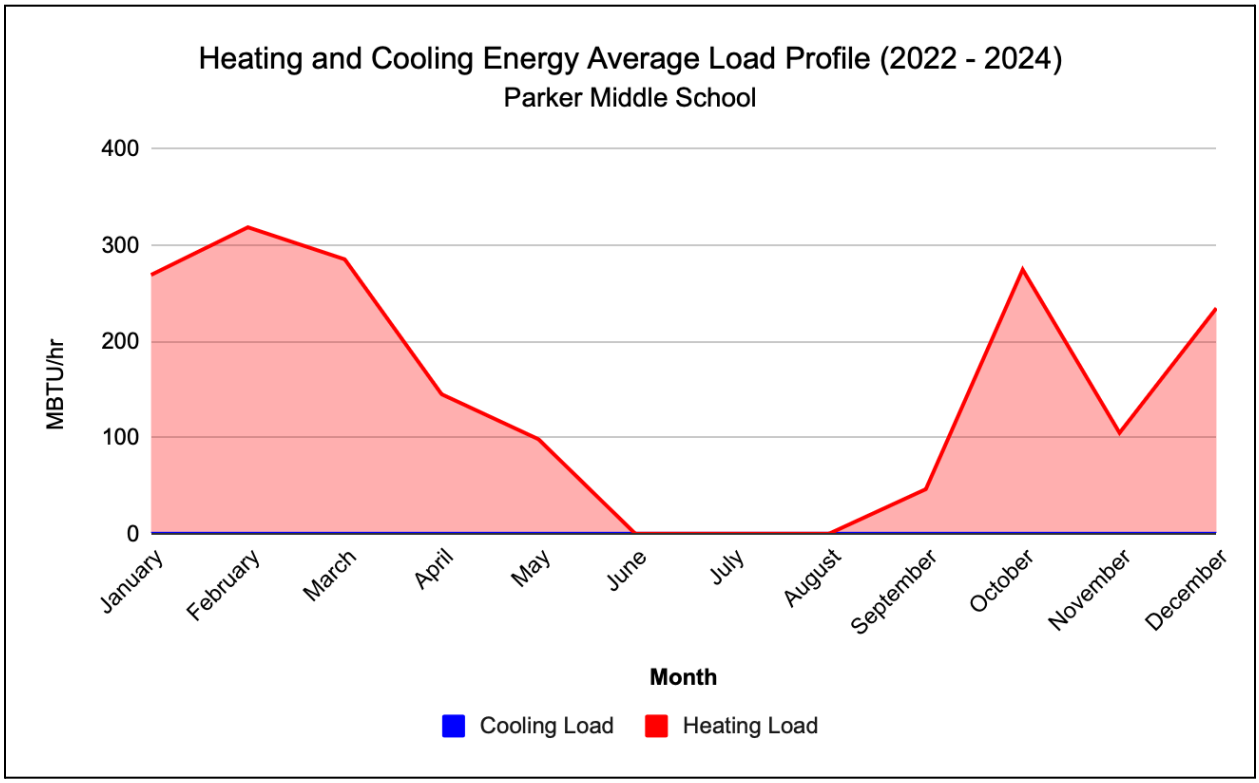


Figure 3.1.6 - BAU Case - Parker Middle - Average Energy Load Profile

Table 3.1.6a - BAU Case - Parker Middle - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	151093
Natural Gas Heating (Therm/yr)	32889
TOTAL Heating/Cooling Energy (MBTU/yr)	3804449

Table 3.1.6b - BAU Case - Parker Middle - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$31,729
Natural Gas Heating Utility ($/yr)	$25,653
TOTAL Heating/Cooling Utility ($/yr)	$57,383

Table 3.1.6c - BAU Case - Parker Middle - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	45
Natural Gas Heating (MTCO2e/yr)	175
TOTAL Heating/Cooling (MTCO2e/yr)	220

3.1.7 Center Elementary School

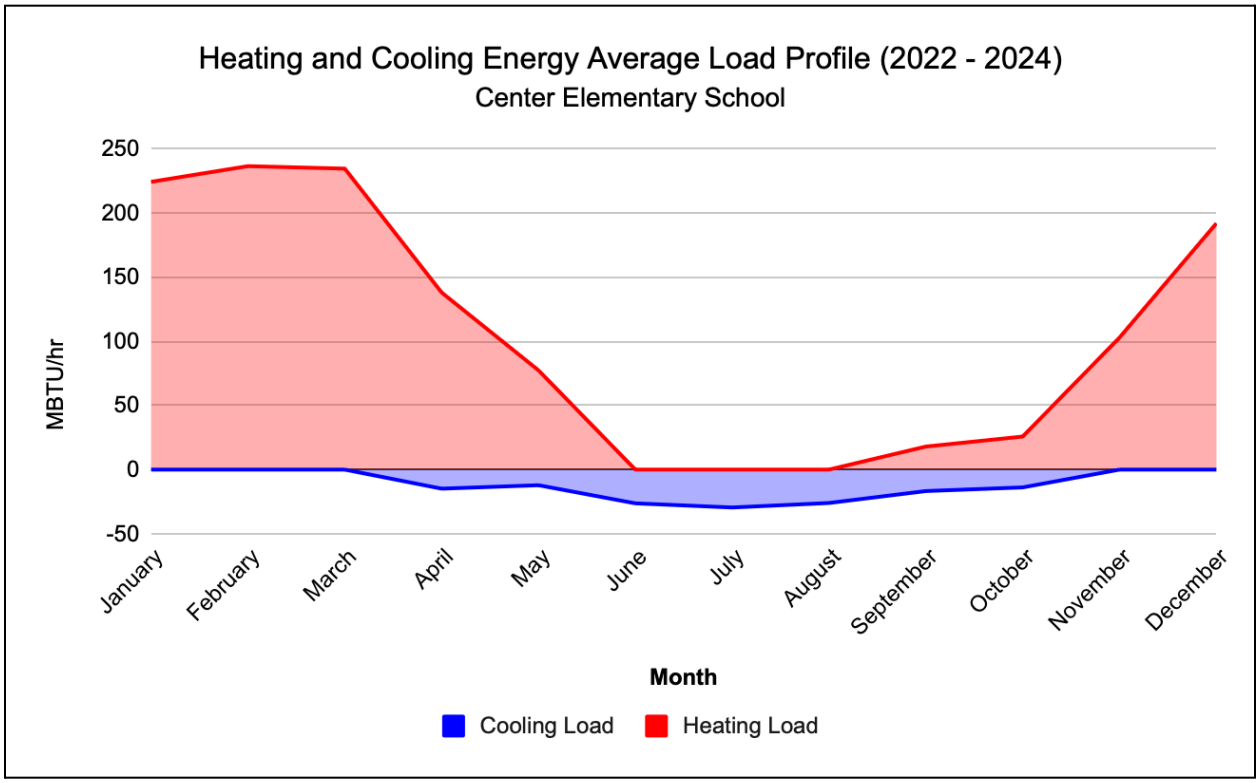


Figure 3.1.7 - BAU Case - Center Elementary - Average Energy Load Profile

Table 3.1.7a - BAU Case - Center Elementary - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	203903
Natural Gas Heating (Therm/yr)	21072
TOTAL Heating/Cooling Energy (MBTU/yr)	2802914

Table 3.1.7b - BAU Case - Center Elementary - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$42,820
Natural Gas Heating Utility ($/yr)	$16,436
TOTAL Heating/Cooling Utility ($/yr)	$59,255

Table 3.1.7c - BAU Case - Center Elementary - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	61
Natural Gas Heating (MTCO2e/yr)	112
TOTAL Heating/Cooling (MTCO2e/yr)	173

3.1.8 South Row Elementary School

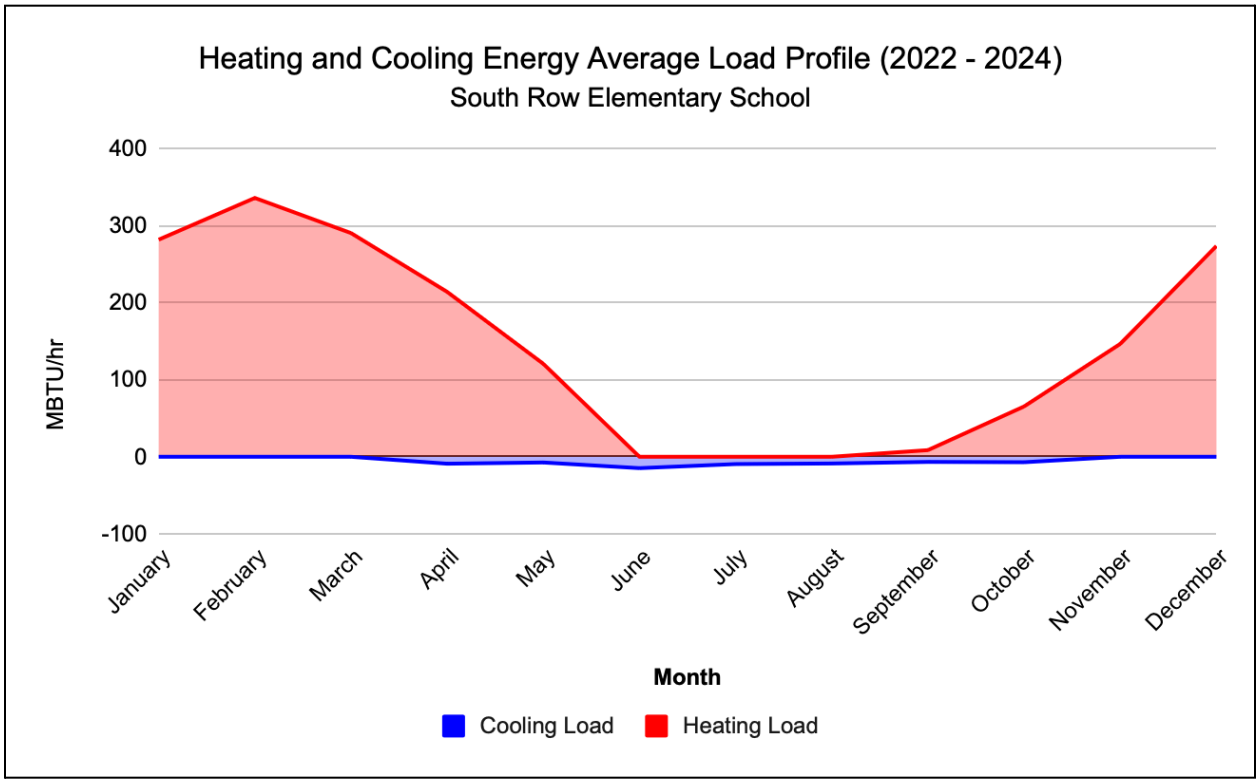


Figure 3.1.8 - BAU Case - South Row Elementary - Average Energy Load Profile

Table 3.1.8a - BAU Case - South Row Elementary - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	108678
Natural Gas Heating (Therm/yr)	32620
TOTAL Heating/Cooling Energy (MBTU/yr)	3632816

Table 3.1.8b - BAU Case - South Row Elementary - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$22,822
Natural Gas Heating Utility ($/yr)	$25,444
TOTAL Heating/Cooling Utility ($/yr)	$48,266

Table 3.1.8c - BAU Case - South Row Elementary - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	32
Natural Gas Heating (MTCO2e/yr)	173
TOTAL Heating/Cooling (MTCO2e/yr)	206

3.1.9 Central Administration Building

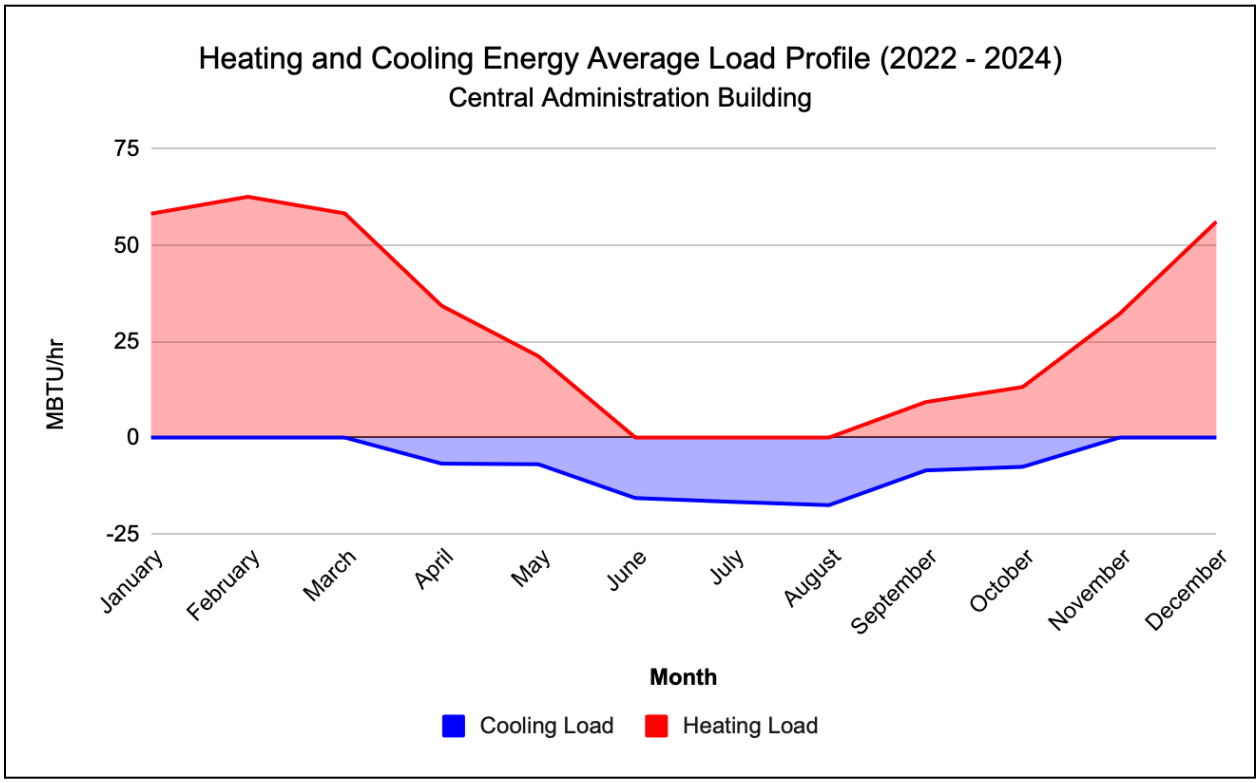


Figure 3.1.9 - BAU Case - Central Administration - Average Energy Load Profile

Table 3.1.9a - BAU Case - Central Administration - Average Energy Consumption (2022-2024)

Electric Heating/Cooling (KWH/yr)	104129
Natural Gas Heating (Therm/yr)	5014
TOTAL Heating/Cooling Energy (MBTU/yr)	856662

Table 3.1.9b - BAU Case - Central Administration - Average Utility Cost (2022 - 2024)

Electric Heating/Cooling Utility ($/yr)	$21,867
Natural Gas Heating Utility ($/yr)	$3,911
TOTAL Heating/Cooling Utility ($/yr)	$25,778

Table 3.1.9c - BAU Case - Central Administration - Average GHG Emissions (2022 - 2024)

Electric Heating/Cooling (MTCO2e/yr)	31
Natural Gas Heating (MTCO2e/yr)	27
TOTAL Heating/Cooling (MTCO2e/yr)	58

3.2 BAU Energy, Operating Costs and Capital Expenses

This subsection estimates energy, operating costs and capital expenses for the BAU case using historical and other available data.

Utility Costs

Using September–October 2024 utility bills, 2024 rates are estimated at $0.78 per therm for natural gas and $0.21 per kWh for electricity, excluding net metering credits. A 2.5% annual escalation for gas and 2.6% for electricity is assumed, per the U.S. Department of Energy's Energy Escalation Rate Calculator, though actual rates may vary with policy changes.

Estimated Maintenance Costs

Town of Chelmsford estimates a total cost of $580,000 in 2024 school maintenance, based on the town's overall budget for building upkeep. With schools comprising 73% of total square footage, this ratio was used to determine their share, which is then allocated to each school by its square footage.

Capital Costs

The capital costs for the BAU case represent the expenditures required to replace and upgrade existing HVAC infrastructure, primarily covering end-of-life replacements, for ensuring continued functionality of HVAC systems. These estimates are generated on a $/sq.ft. basis to provide a baseline for comparison with electrification scenario.

Table 3.3 - BAU Case - Estimated Annual Maintenance Costs and Capital Expenses

Facility	Maintenance Cost	Capital Costs
Chelmsford HS	$200,729	$2,858,820
Byam	$47,420	$675,360
Community / Westlands	$26,049	$371,000
Harrington	$47,420	$675,360
McCarthy	$101,108	$1,440,000
Parker	$73,725	$1,050,000
Center Elementaty	$34,823	$495,950
South Row	$41,572	$592,070
Central Admin	$7,156	$101,920
TOTAL	**$580,000**	**$8,260,480**

4. Energy Conservation Measures

Energy Conservation Measures (ECMs) are targeted building upgrades and operational improvements that enhance energy efficiency and reduce energy costs. These typically include lighting system upgrades, HVAC optimizations, building envelope improvements, energy management system enhancements, and renewable energy integration.

In 2013, Chelmsford entered into an Energy Savings Performance Contract with Johnson Controls, implementing 26 ECMs across municipal facilities. This initiative has resulted in $967,918 in verified cost avoidance in Year 9 alone, with total savings exceeding $7.6 million. ESPCs allow municipalities to implement energy upgrades without upfront capital costs. The 2024 Measurement and Verification (M&V) report identifies additional opportunities to further improve energy efficiency. Recommended measures include expanding demand-controlled ventilation , optimizing heating and cooling schedules, enhancing insulation, and increasing solar photovoltaic (PV) capacity. These recommendations align with best practices recommended by organizations such as the *US National Renewable Energy Laboratory (NREL)*, which emphasize prioritizing efficiency improvements before renewable energy investments. The recommendations summarized in Table 4 are based on a review of existing documentation and the 2024 M&V Report.

Table 4 - ECM Recommendations

Facility	Recommendations
Chelmsford High	- Optimize HVAC Scheduling - Install Demand-Controlled Ventilation
Byam	- Improve Weather Sealing - Upgrade HVAC Systems - Enhance Pipe & Valve Insulation
Community / Westlands	- Investigate Battery Storage Integration - Install Smart Energy Meters - Upgrade HVAC Controls
Harrington	- Upgrade Roof Insulation - Improve Ventilation Efficiency - Expand Heating and Cooling Controls
McCarthy	- Chiller Optimization - Improve Window Insulation
Parker	- Upgrade Building Automation System Controls - Optimize HVAC Scheduling - Expand High-Efficiency Motors
Center Elementary	- Implement Heat Pump Water Heaters - Improve Energy Recovery Ventilators - Upgrade to LED Smart Lighting
South Row	- Optimize HVAC Efficiency - Upgrade Refrigeration Units - Install High-Efficiency Transformers
Central Admin	- Improve Weatherproofing & Insulation - Assess Transition to Heat Pump-Based Heating - Implement Smart Energy Management Systems

5. Solar Photovoltaic and Islanding Overview

Eight of Chelmsford's nine public school facilities have Solar Photovoltaic (PV) systems, most requiring replacement or upgrades by 2034 to maintain efficiency and reliability.

Islanding capabilities, enabling independent operation during power outages, are feasible for all school buildings. Implementing islanding requires detailed engineering evaluations to assess infrastructure upgrades, including switchgear and electrical systems. Planning for islanding should precede major PV system replacements.

The Central Administration Building lacks a PV system. Due to limited rooftop space, a conventional rooftop system may not be viable, but a detailed engineering assessment could evaluate a small-scale rooftop or ground-mounted system to support critical functions (e.g., computing, security) during outages.

Per the 2024 Measurement and Verification report, Chelmsford's school PV arrays produced 2,365 MWh of electricity in the latest performance period. Table 5 summarizes PV system capacity and production.

Table 5 - Solar Photovoltaic and Islanding Summary

Facility	Year Installed	Solar Capacity (kW)	Solar Production (MWh)
Chelmsford High	2007	400	282.0
Byam	2012	250	232.2
Community / Westlands	2014	150	118.6
Harrington	2005	300	388.4
McCarthy	2002	350	383.7
Parker	2009	200	235.3
Center Elementary	2015	100	97.9
South Row	1999	180	184.5
Central Admin	N/A	N/A	N/A

6. Path To Electrification

6.1 General Philosophy

Electrifying school buildings involves various strategies, with costs depending on system design, market conditions, and each building's renovation needs. Given the diverse ages and conditions of Chelmsford's nine schools, this study uses an average cost-per-unit approach to provide a baseline for comparison, though actual costs may vary significantly. In particular, given the age of existing electrical infrastructure, detailed assessments of electrical backbones and potential upgrades are required before implementing electrified HVAC systems. Therefore, cost of these infrastructure upgrades are estimated on a dollars-per-square-foot basis to maintain consistency across all facilities.

This electrification roadmap study provides a strategic framework for planning, focusing on life cycle cost comparisons, BAU scenarios, and electrification strategies. The methodology is consistent for planning, determining heating requirements, analyzing utility data, and designing systems to balance energy efficiency and reliability.

6.2 Options Considered

This roadmap focuses on Air Source Heat Pumps (ASHPs) for space heating/cooling, supported by electric boilers and ASHP-based water heating for Domestic Hot Water (DHW), selected for scalability, energy efficiency, and suitability across all nine facilities. For all schools, ASHPs are sized at 150% of peak thermal load capacity to ensure reliability through redundancy, as thermal load exceeds cooling load in all cases. This can be achieved using two units, each covering 75% of the peak thermal load, or three units, each covering 50%, providing 75% or 100% capacity if one unit fails. Similarly, DHW systems are priced for 150% of estimated peak demand. Cost estimates are agnostic to the specific redundancy approach, ensuring a consistent comparison basis across facilities.

Thermal load and cost estimations used in the study are based on actual energy usage based on historical data (2022–2024, per Section 3). Despite ASHPs' capability to provide cooling, the analysis does not include adding cooling (i.e., increased load, costs, etc) to facilities that are currently not equipped for cooling.

Ground Source Heat Pumps (GSHPs) and other specialized systems were excluded from analysis, as they require detailed assessments and cost estimates beyond the scope of this study. It is important to note that ASHPs offer lower installed costs compared to GSHPs.

6.3 Recommended Electrification Roadmap

The recommended electrification timeline, detailed in Table 6.3, is devised based on the remaining useful life of existing equipment to maximize current investments. Equipment life expectancy is assumed to be 20 years, and this timeline aligns with the installed dates of current systems (e.g., new boilers installed at Chelmsford High School in 2023) and currently planned replacements (e.g., new boilers installed at McCarthy Middle School in 2026). The approach ensures consistency across schools for evaluating infrastructure upgrades, with the following exception. While the electrified system to be installed in 2028 will reach end-of-life in 2048, replacement costs for 2048 are excluded from the study, assuming repairs and timely maintenance will extend system life beyond 20 years, as often observed with infrastructure systems.

Table 6.3 - Recommended Electrification Timeline

Building	Conversion Year
Chelmsford High School	2,043
Byam Elementary School	2,042
Chelmsford Community Education	2,044
Harrington Elementary School	2,044
McCarthy Middle School	2,046
Parker Middle School	2,028
Center Elementary School	2,043
South Row Elementary School	2,036
Central Administration Building	2,037

6.4 Electrification Details for Individual Facilities

6.4.1 Chelmsford High School

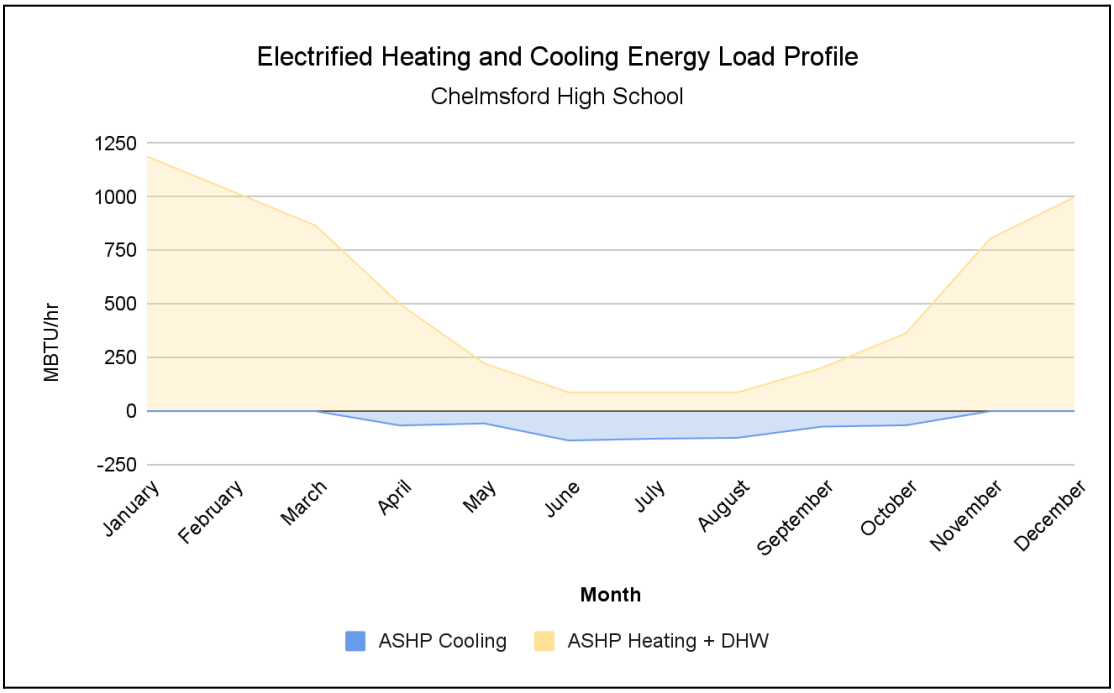


Figure 6.4.1 - Electrified Case - Chelmsford High - Energy Load Profile

Table 6.4.1a - BAU Vs Electrified - Chelmsford High - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	921098	1613111	692013	75.13%
Natural Gas Heating (Therm/yr)	90308	0	-90308	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	12173695	5504161	-6669534	-54.79%

Table 6.4.1b - BAU Vs Electrified - Chelmsford High - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$193,431	$338,753	$145,323	75.13%
Natural Gas Heating Utility ($/yr)	$70,440	$0	-$70,440	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$263,871	$338,753	$74,883	28.38%

Table 6.4.1c - BAU Vs Electrified - Chelmsford High - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	275	481	207	75.13%
Natural Gas Heating (MTCO2e/yr)	479	0	-479	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	754	481	-273	-36.16%

6.4.2 Byam Elementary School

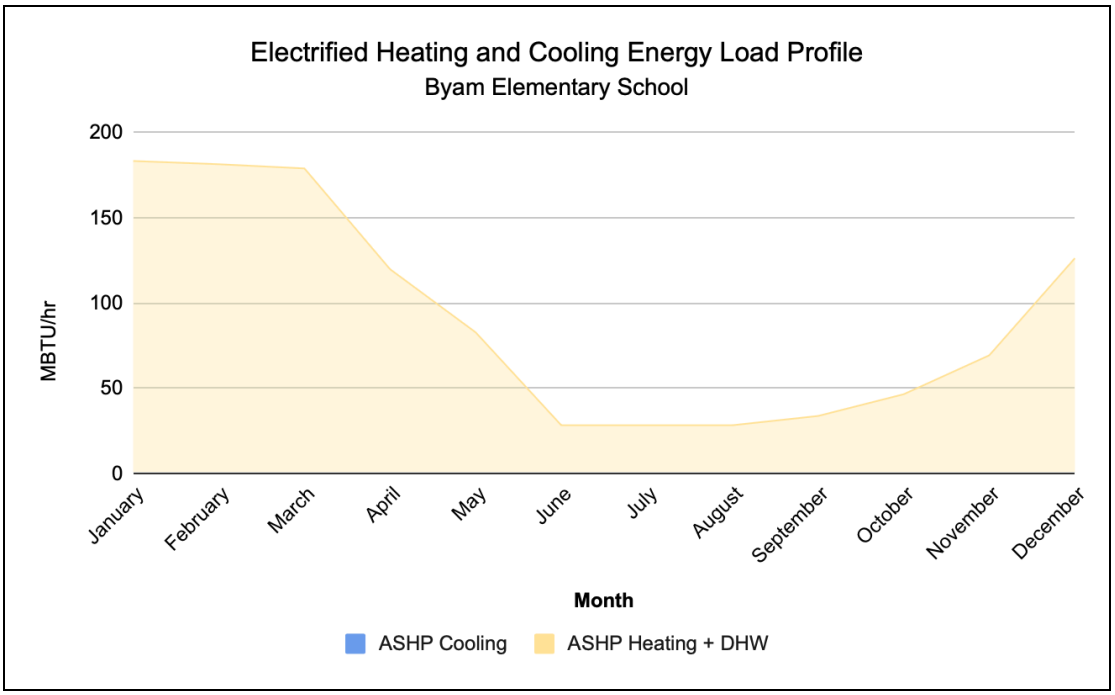


Figure 6.4.2 - Electrified Case - Byam Elementary - Energy Load Profile

Table 6.4.2a - BAU Vs Electrified - Byam Elementary - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	35551	327194	291644	820.36%
Natural Gas Heating (Therm/yr)	14806	0	-14806	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	1601923	1116432	-485491	-30.31%

Table 6.4.2b - BAU Vs Electrified - Byam Elementary - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$7,466	$68,711	$61,245	820.36%
Natural Gas Heating Utility ($/yr)	$11,549	$0	-$11,549	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$19,014	$68,711	$49,696	261.36%

Table 6.4.2c - BAU Vs Electrified - Byam Elementary - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	11	98	87	820.36%
Natural Gas Heating (MTCO2e/yr)	79	0	-79	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	89	98	8	9.49%

6.4.3 Chelmsford Community Education

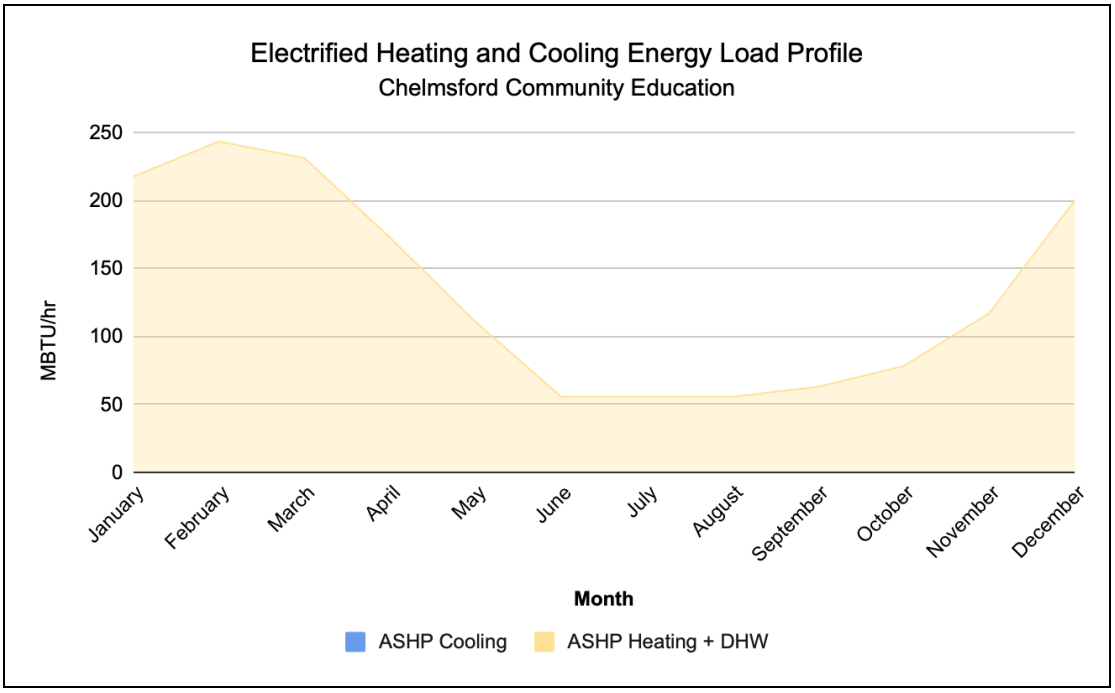


Figure 6.4.3 - Electrified Case - Community Education - Energy Load Profile

Table 6.4.3a - BAU Vs Electrified - Community Education - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	40786	548120	507334	1243.90%
Natural Gas Heating (Therm/yr)	18348	0	-18348	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	1973996	1870262	-103735	-5.26%

Table 6.4.3b - BAU Vs Electrified - Community Education - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$8,565	$115,105	$106,540	1243.90%
Natural Gas Heating Utility ($/yr)	$14,312	$0	-$14,312	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$22,877	$115,105	$92,229	403.16%

Table 6.4.3c - BAU Vs Electrified - Community Education - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	12	164	151	1243.90%
Natural Gas Heating (MTCO2e/yr)	97	0	-97	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	110	164	54	49.34%

6.4.4 Harrington Elementary School

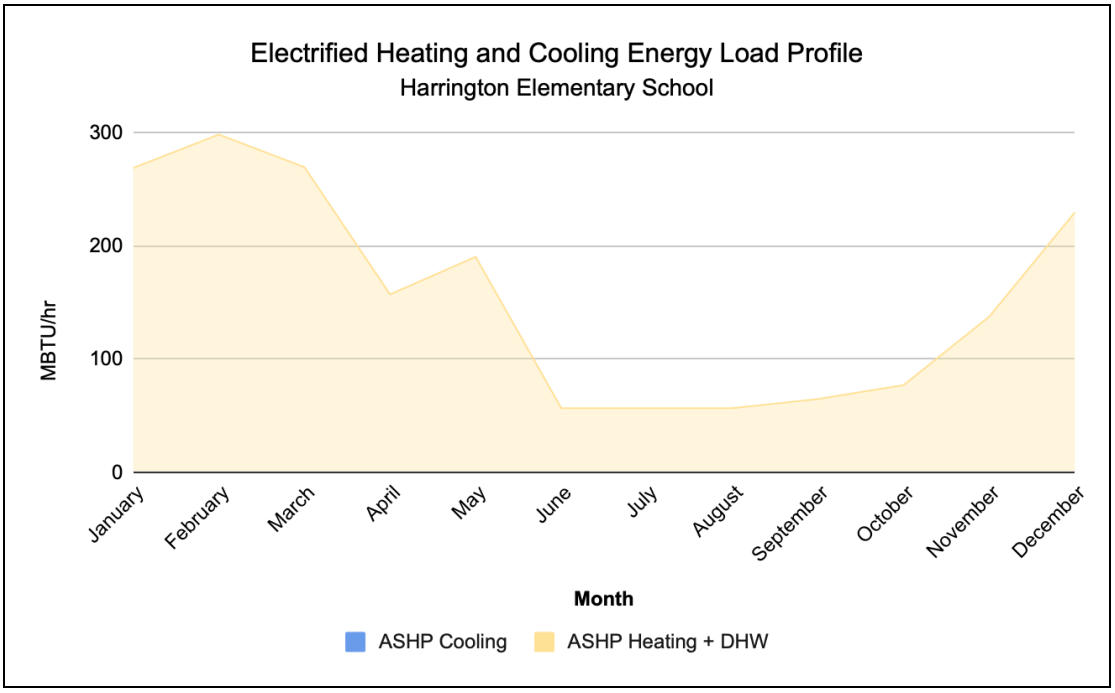


Figure 6.4.4 - Electrified Case - Harrington Elementary - Energy Load Profile

Table 6.4.4a - BAU Vs Electrified - Harrington Elemen. - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	55861	597287	541426	969.23%
Natural Gas Heating (Therm/yr)	23184	0	-23184	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	2509037	2038027	-471010	-18.77%

Table 6.4.4b - BAU Vs Electrified - Harrington Elementary - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$11,731	$125,430	$113,699	969.23%
Natural Gas Heating Utility ($/yr)	$18,084	$0	-$18,084	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$29,815	$125,430	$95,616	320.70%

Table 6.4.4c - BAU Vs Electrified - Harrington Elementary - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	17	178	162	969.23%
Natural Gas Heating (MTCO2e/yr)	123	0	-123	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	140	178	39	27.60%

6.4.5 McCarthy Middle School

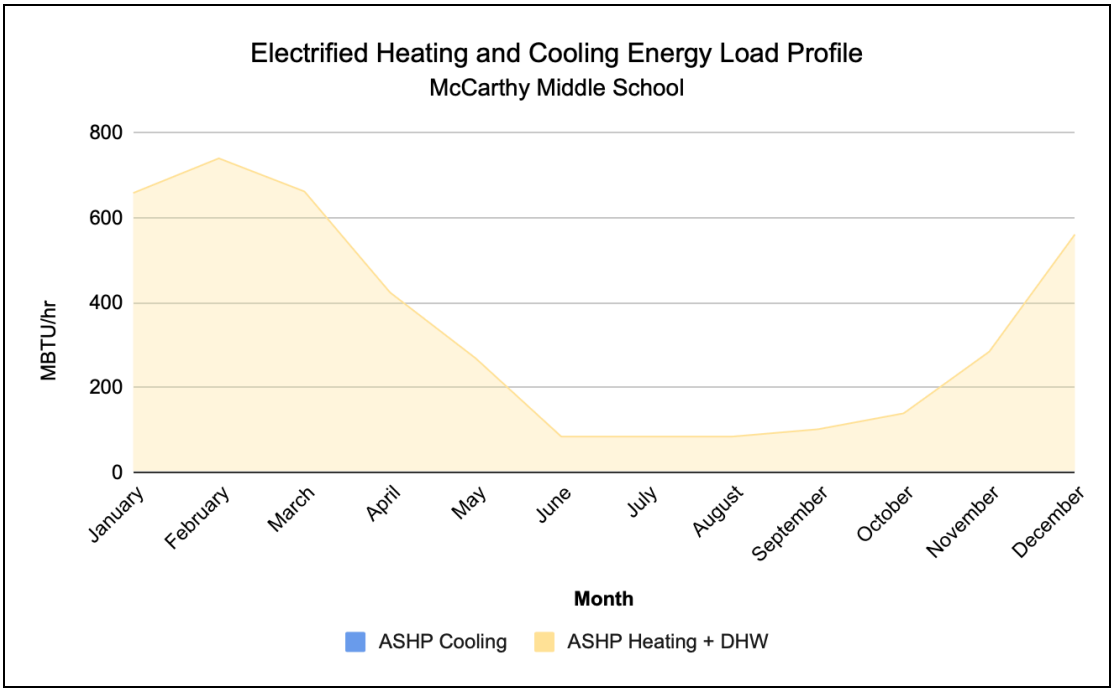


Figure 6.4.5 - Electrified Case - McCarthy Middle School - Energy Load Profile

Table 6.4.5a - BAU Vs Electrified - McCarthy Middle - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	149605	1108544	958939	640.98%
Natural Gas Heating (Therm/yr)	59177	0	-59177	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	6428213	3782506	-2645707	-41.16%

Table 6.4.5b - BAU Vs Electrified - McCarthy Middle - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$31,417	$232,794	$201,377	640.98%
Natural Gas Heating Utility ($/yr)	$46,158	$0	-$46,158	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$77,575	$232,794	$155,219	200.09%

Table 6.4.5c - BAU Vs Electrified - McCarthy Middle - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	45	331	286	640.98%
Natural Gas Heating (MTCO2e/yr)	314	0	-314	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	359	331	-28	-7.76%

6.4.6 Parker Middle School

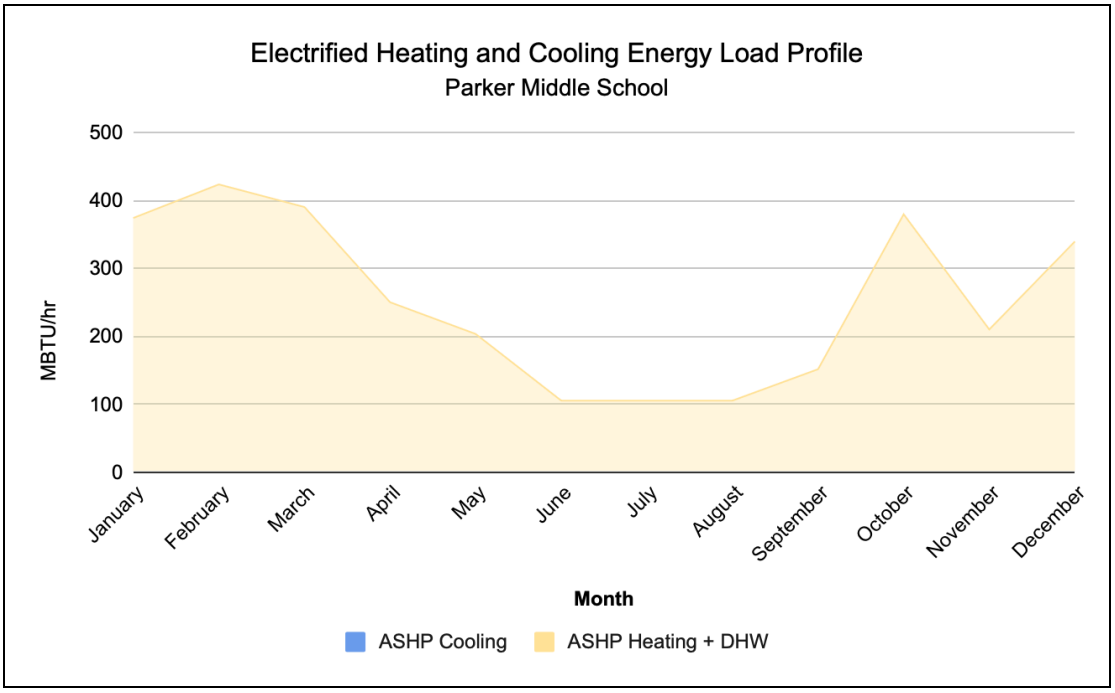


Figure 6.4.6 - Electrified Case - Parker Middle - Energy Load Profile

Table 6.4.6a - BAU Vs Electrified - Parker Middle - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	151093	1040291	889198	588.51%
Natural Gas Heating (Therm/yr)	32889	0	-32889	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	3804449	3549618	-254831	-6.70%

Table 6.4.6b - BAU Vs Electrified - Parker Middle - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$31,729	$218,461	$186,732	588.51%
Natural Gas Heating Utility ($/yr)	$25,653	$0	-$25,653	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$57,383	$218,461	$161,078	280.71%

Table 6.4.6c - BAU Vs Electrified - Parker Middle - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	45	310	265	588.51%
Natural Gas Heating (MTCO2e/yr)	175	0	-175	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	220	310	91	41.36%

6.4.7 Center Elementary School

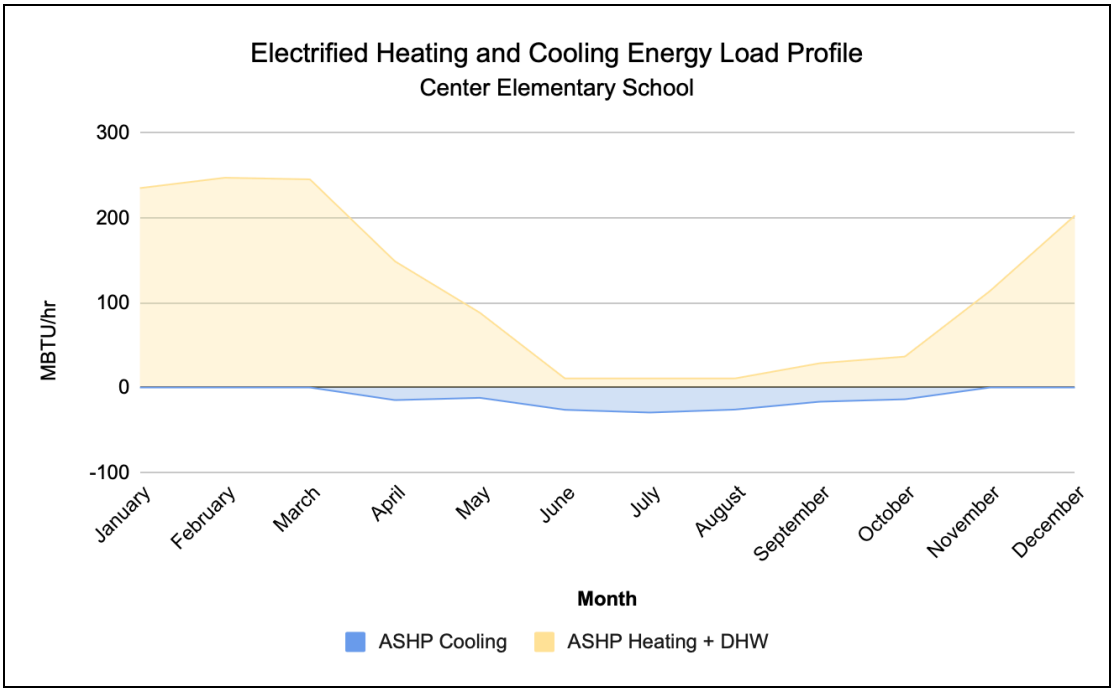


Figure 6.4.7 - Electrified Case - Center Elementary - Energy Load Profile

Table 6.4.7a - BAU Vs Electrified - Center Elementary - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	203903	304629	100726	49.40%
Natural Gas Heating (Therm/yr)	21072	0	-21072	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	2802914	1039436	-1763479	-62.92%

Table 6.4.7b - BAU Vs Electrified - Center Elementary - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$42,820	$63,972	$21,152	49.40%
Natural Gas Heating Utility ($/yr)	$16,436	$0	-$16,436	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$59,255	$63,972	$4,717	7.96%

Table 6.4.7c - BAU Vs Electrified - Center Elementary - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	61	91	30	49.40%
Natural Gas Heating (MTCO2e/yr)	112	0	-112	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	173	91	-82	-47.35%

6.4.8 South Row Elementary School

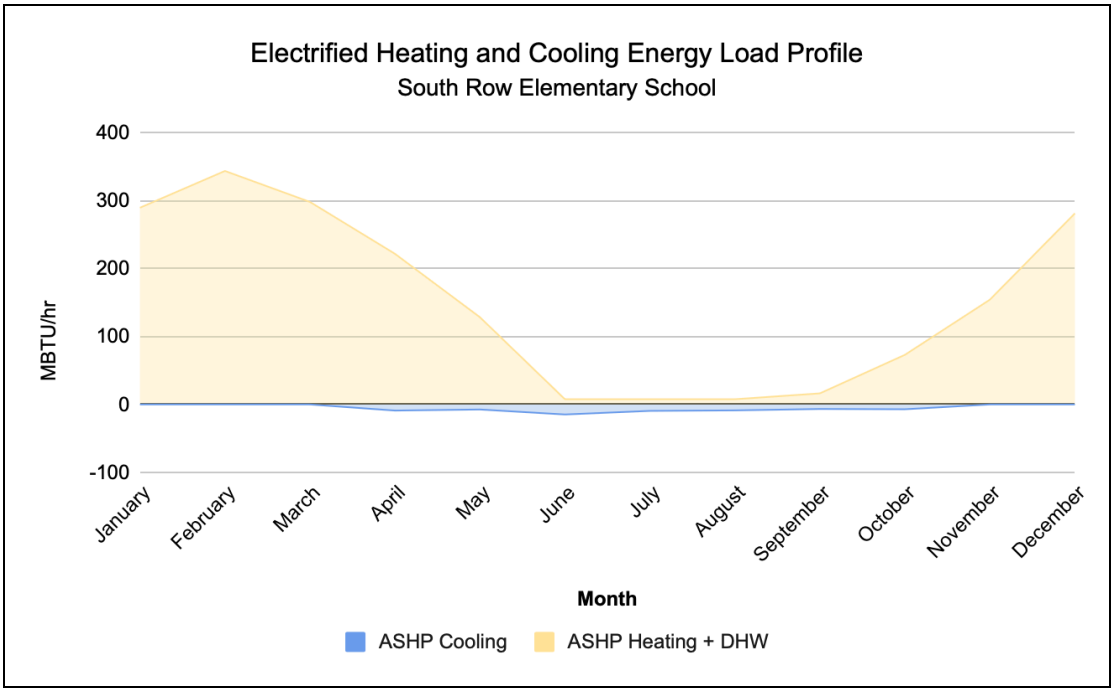


Figure 6.4.8 - Electrified Case - South Row Elementary - Energy Load Profile

Table 6.4.8a - BAU Vs Electrified - South Row Elementary - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	108678	354512	245834	226.20%
Natural Gas Heating (Therm/yr)	32620	0	-32620	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	3632816	1209646	-2423170	-66.70%

Table 6.4.8b - BAU Vs Electrified - South Row Elementary - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$22,822	$74,448	$51,625	226.20%
Natural Gas Heating Utility ($/yr)	$25,444	$0	-$25,444	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$48,266	$74,448	$26,182	54.24%

Table 6.4.8c - BAU Vs Electrified - South Row Elementary - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	32	106	73	226.20%
Natural Gas Heating (MTCO2e/yr)	173	0	-173	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	206	106	-100	-48.52%

6.4.9 Central Administration Building

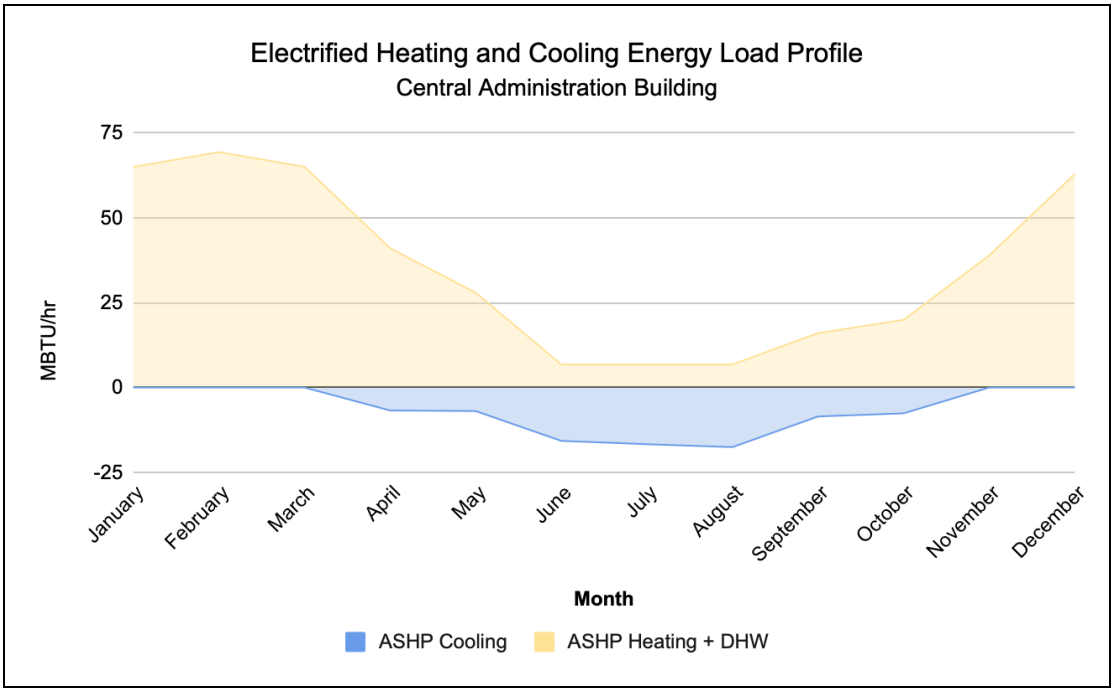


Figure 6.4.9 - Electrified Case - Central Admin - Energy Load Profile

Table 6.4.9a - BAU Vs Electrified - Central Admin - Energy Consumption Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (KWH/yr)	104129	117326	13197	12.67%
Natural Gas Heating (Therm/yr)	5014	0	-5014	-100.00%
TOTAL Heating/Cooling Energy (MBTU/yr)	856662	400332	-456330	-53.27%

Table 6.4.9b - BAU Vs Electrified - Central Admin - Utility Costs Comparison (2024 $)

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling Utility ($/yr)	$21,867	$24,638	$2,771	12.67%
Natural Gas Heating Utility ($/yr)	$3,911	$0	-$3,911	-100.00%
TOTAL Heating/Cooling Utility ($/yr)	$25,778	$24,638	-$1,139	-4.42%

Table 6.4.9c - BAU Vs Electrified - Central Admin - GHG Emissions Comparison

	BAU	Electrified	Difference	Change (%)
Electric Heating/Cooling (MTCO2e/yr)	31	35	4	12.67%
Natural Gas Heating (MTCO2e/yr)	27	0	-27	-100.00%
TOTAL Heating/Cooling (MTCO2e/yr)	58	35	-23	-39.30%

6.5 Estimated Electrification Costs

Converting gas-fired systems to electrified systems involves removing High-Temperature Hot Water (HTHW) infrastructure and installing ASHP-based Low-Temperature Hot Water (LTHW) systems, affecting central equipment (e.g., AHUs, Rooftop Units, RTUs) and HVAC distribution (e.g., radiators, reheat coils). Structural upgrades may also be needed for ASHP placement, but require detailed assessments with finalized designs for cost assessments. Due to the aging infrastructure, electrical backbone upgrades are recommended for all facilities prior to conversion to electrified HVAC systems.

6.5.1 Building Conversion Cost

Building conversion costs are calculated per sq. ft., considering building age, usage, and industry data. Older buildings require more retrofitting, increasing costs. The estimated cost is $37.50 per sq. ft., accounting for inflation, Massachusetts labor rates, and materials, but excluding structural reinforcements or unforeseen repairs. Table 6.5.1 presents the estimated building conversion costs for each facility.

Table 6.5.1 - Estimated Building Conversion Cost Summary

Building	Size (Sq. Ft.)	Cost (2024 $)	Conversion Year	Future Cost
Chelmsford High School	285,882	$10,720,575	2,043	$17,138,449.21
Byam Elementary School	67,536	$2,532,600	2,042	$3,949,991.67
Chelmsford Community Education	37,100	$1,391,250	2,044	$2,279,725.12
Harrington Elementary School	67,536	$2,532,600	2,044	$4,149,960.00
McCarthy Middle School	144,000	$5,400,000	2,046	$9,296,485.55
Parker Middle School	105,000	$3,937,500	2,028	$4,346,263.26
Center Elementary School	49,595	$1,859,813	2,043	$2,973,189.60
South Row Elementary School	59,207	$2,220,263	2,036	$2,986,006.22
Central Administration Building	10,192	$382,200	2,037	$526,866.92
TOTAL		**$30,976,800**		

6.5.2 Energy Plan Cost

Energy plant costs include ASHP equipment expenses, calculated using average per-ton costs, and electrical backbone upgrades based on per-sq.-ft. estimates. Costs are derived from industry data, accounting for Massachusetts labor rates, with installation costs assumed at 100% of equipment costs. Electrical upgrades require detailed engineering to assess load capacity, transformers, and service modifications, which are beyond this study's scope. Per National Grid, grid capacity assessments and transformer upgrade costs await detailed designs and are the town's responsibility, also excluded from estimates.

Table 6.5.2 presents the estimated energy plant costs for each facility.

Table 6.5.2 - Estimated Energy Plant Costs Summary

Building	Total Cost (2024 $)	Conversion Year	Future Cost
Chelmsford High School	$5,920,669	2,043	$9,465,078
Byam Elementary School	$469,588	2,042	$732,397
Chelmsford Community Education	$318,450	2,044	$521,817
Harrington Elementary School	$1,482,959	2,044	$2,430,001
McCarthy Middle School	$3,115,938	2,046	$5,364,309
Parker Middle School	$2,180,050	2,028	$2,406,367
Center Elementary School	$1,177,116	2,043	$1,881,797
South Row Elementary School	$1,420,096	2,036	$1,909,871
Central Administration Building	$374,078	2,037	$515,670
TOTAL	**$16,458,944**		

6.5.3 Estimated Maintenance Costs

Annual maintenance costs for electrified systems cover ASHPs, electric boilers, and HVAC distribution, with a 30% miscellaneous factor for unchanged BAU items. Assumptions include $50 per ton per year for ASHPs and HVAC components, and $2,500 per electric boiler per year, derived from industry data. Solar Photovoltaic (PV) maintenance is excluded due to an existing town contract. Electrified systems typically reduce maintenance costs compared to gas-fired boilers, though savings depend on system complexity and contracts. Table 6.5.3 provides the estimated maintenance cost for each facility, where the costs are shown in 2024 dollars.

Table 6.5.3 - Estimated Electrified Maintenance Costs Summary

Building	Size (Sq. Ft.)	Cost
Chelmsford High School	285,882	$76,519
Byam Elementary School	67,536	$18,626
Chelmsford Community Education	37,100	$12,715
Harrington Elementary School	67,536	$19,726
McCarthy Middle School	144,000	$43,532
Parker Middle School	105,000	$28,617
Center Elementary School	49,595	$15,947
South Row Elementary School	59,207	$21,671
Central Administration Building	10,192	$5,447
TOTAL		**$242,800**

7 Life Cycle Cost Analysis

7.1 Overview

The Life Cycle Cost Analysis (LCCA) compares the long-term financial impacts of maintaining fossil fuel-based HVAC systems (Business-as-Usual, BAU) versus transitioning to electrified systems over a 28-year period (2024–2051), aligning with Chelmsford's carbon neutrality goal by 2050. It includes utility, maintenance, and capital costs, comparing financial trade-offs for decision-making. Present value costs are in 2024 dollars, using a 3.0% real discount rate. Utility cost escalations are 2.5% per year for electricity and 2.6% for natural gas, per the U.S. Department of Energy's Energy Escalation Rate Calculator. The LCCA excludes incentives, carbon pricing, or external funding, which could affect outcomes.

Table 7.1.1 - Life Cycle Cost Analysis (2024 - 2051)

Cost Type	BAU Case	Electrified Case	Difference
Electricity Cost	$10,411,733	$20,841,773	$10,430,040
Natural Gas Cost*	$6,495,613	$3,980,690	-$2,514,924
Total Utility Cost	$16,907,347	$24,822,463	$7,915,116
Maintenance Costs	$16,240,000	$12,563,997	-$3,676,003
Investment Cost	$8,260,480	$47,435,744	$39,175,264
Life Cycle Cost (28 yrs)	$41,407,827	$84,822,204	$43,414,377

*Natural gas costs in the Electrified Case reflect use of gas systems during the transition period.

Table 7.1.1 compares BAU and electrified scenarios, showing a 28 year life cycle cost of $41.4 million versus $84.8 million for electrification, a $43.4 million difference. Electrification eliminates natural gas costs (after conversion of all facilities) and reduces maintenance expenses, but increases electricity costs and requires higher capital investment ($47.4 million vs. $8.3 million). See Figure 7.1.1 for a graphical comparison.

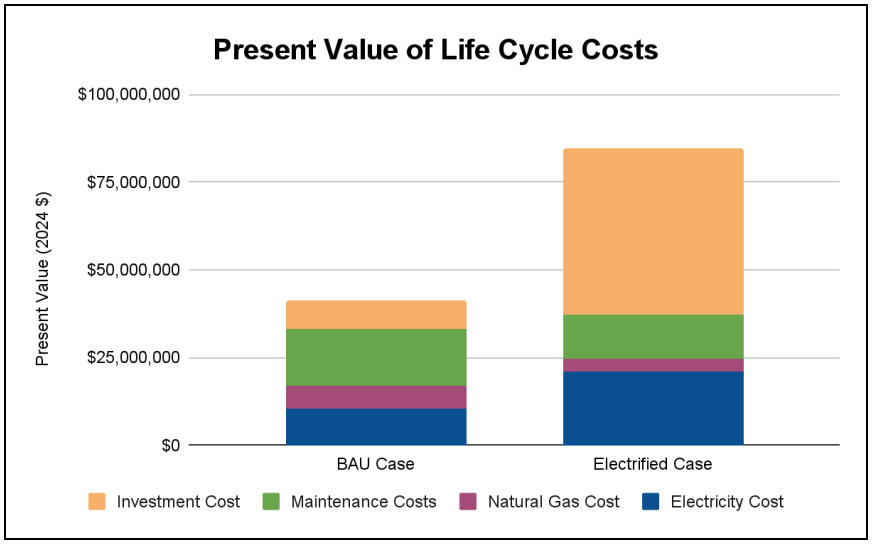


Figure 7.1.1 - Present Value Comparison for BAU and Electrified Cases

7.2 Economic Performance Comparison

This subsection examines cost trends over 2024–2051, focusing on utility, capital, and operating expenses under BAU and electrified scenarios.

7.2.1 Utility Cost Trends

Using September–October 2024 utility bills, 2024 rates are estimated at $0.78 per therm for natural gas and $0.21 per kWh for electricity, excluding net metering credits. Annual escalations of 2.5% for gas and 2.6% for electricity are assumed, per the U.S. Department of Energy's Energy Escalation Rate Calculator, though actual rates may vary with policy changes. Based on these rates, Figure 7.2.1 shows projected price trends for natural gas and electricity.

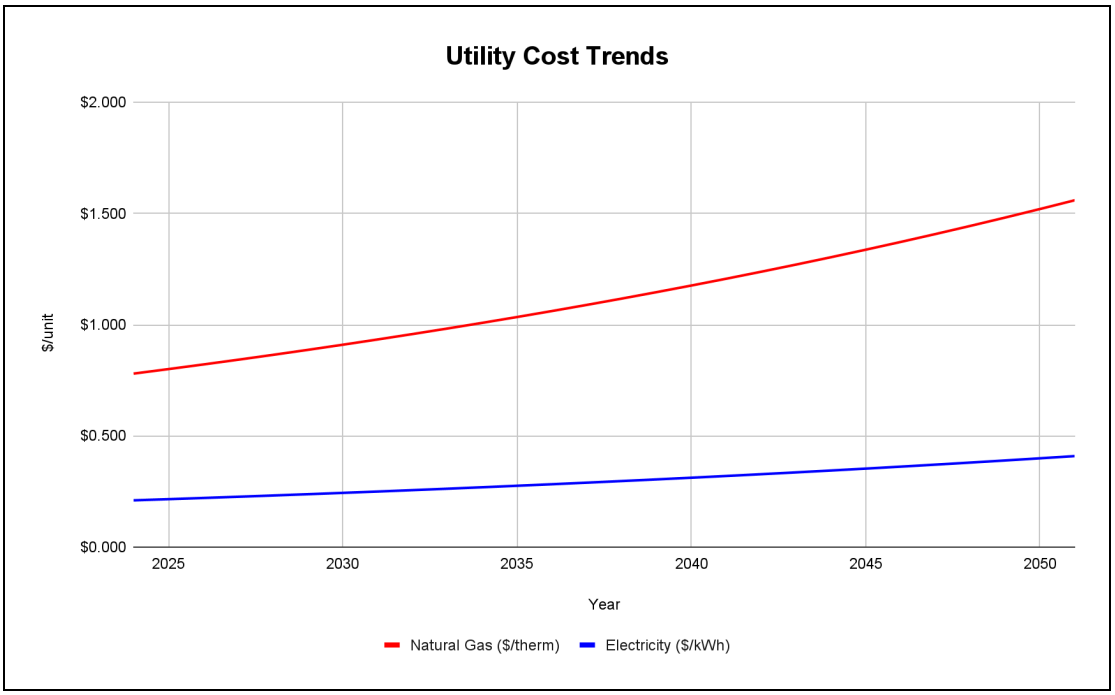


Figure 7.2.1 - Utility Cost Forecast

For LCCA projections, BAU costs reflect both energy sources, while the electrified case includes interim natural gas costs for facilities not yet electrified until 2046 (per Table 6.3), transitioning fully to electricity thereafter. Advancements in electrification infrastructure (e.g., grid-scale renewables) could reduce electricity costs, potentially lowering the cost difference. Utility rates significantly influence LCCA results, underscoring the need to monitor energy market trends and technological developments when planning electrification.

7.2.2 Capital Costs

BAU case incurs low, periodic costs for replacing gas-fired boilers and HVAC components. Electrification requires significant investments during conversion years (2028–2046, per Table 6.3) for ASHP installations, electrical upgrades, and retrofits. Grants or incentives, excluded here, could reduce electrification costs. Figure 7.2.2 shows cumulative capital costs in 2024 dollars over 2024–2051.

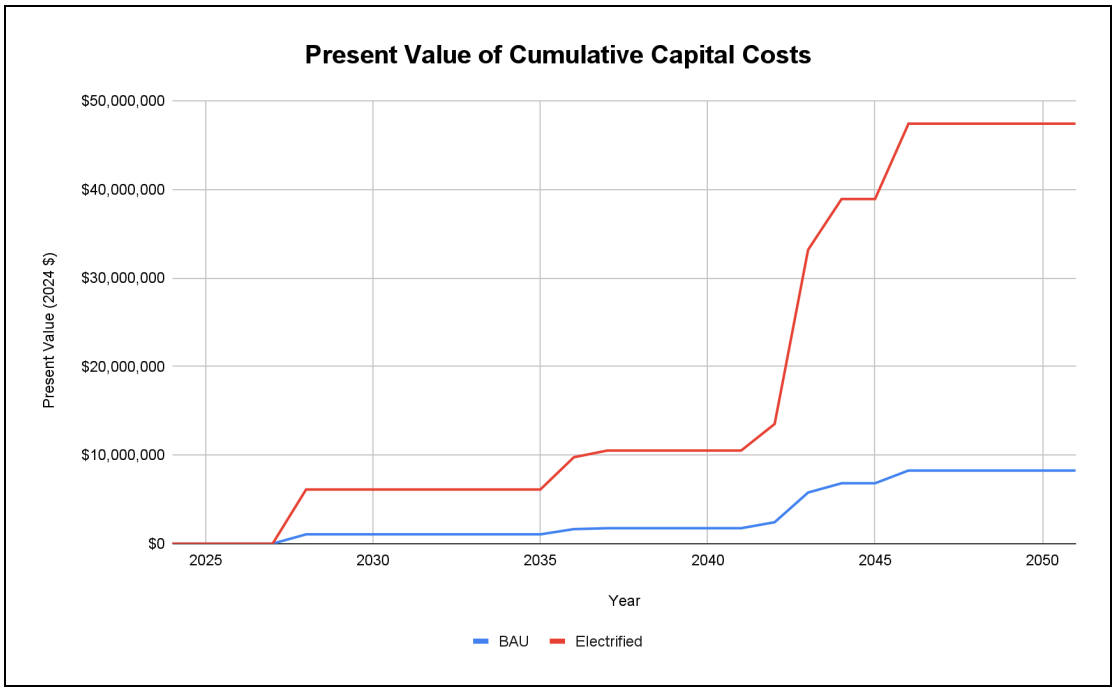


Figure 7.2.2 - Present Value Comparison of Cumulative Capital Costs

7.2.3 Annual Operating Costs

Figure 7.2.3 provides a comparison of annual operating costs (utility and maintenance) in 2024 dollars over 2024–2051. BAU costs rise due to increasing gas and electricity prices and consistent maintenance. Electrification lowers maintenance costs but increases electricity expenses, resulting in higher operating costs by 2051.

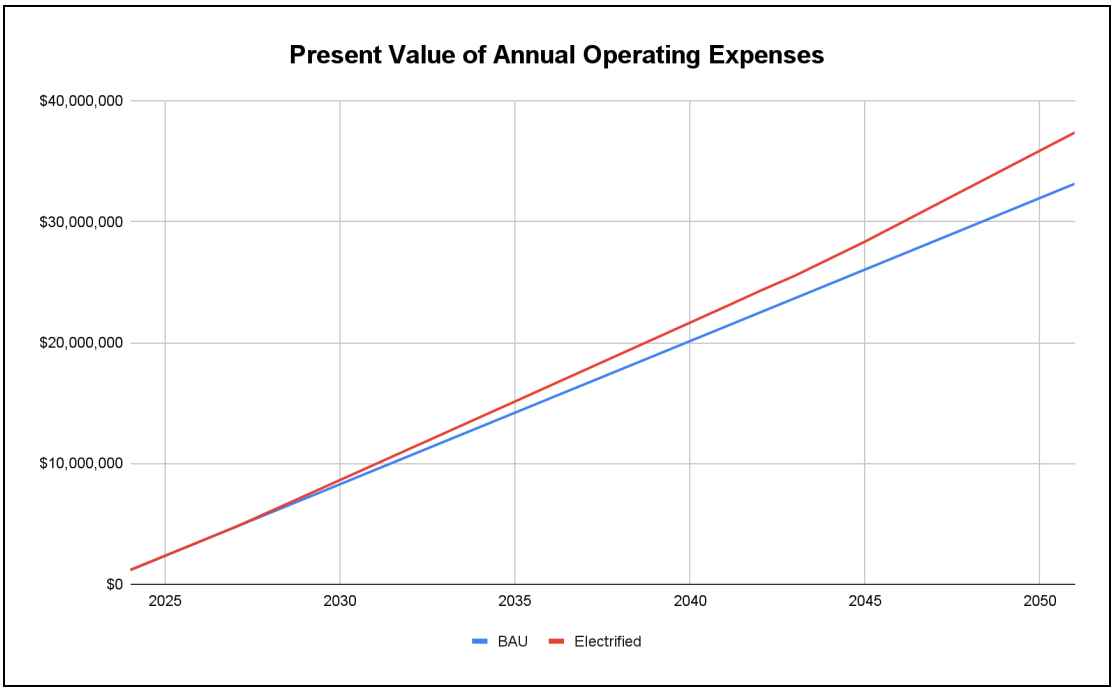


Figure 7.2.3 - Annual Operating Expenses

The BAU case shows a steady increase in operating costs, driven by rising natural gas and electricity prices and consistent maintenance expenses for gas-fired systems. While the Electrification case lowers maintenance costs (see Table 7.2.1), by 2051, the Electrification case has higher total operating costs, primarily due to electricity expenses.

Table 7.2.1 - Present Value of Annual Operating Expenses in Year 2051

Expense Type	BAU Case	Electrified Case	Difference
Electricity	$371,848	$1,262,313	$890,465
Natural Gas	$231,986	$0	-$231,986
Maintenance	$580,000	$242,800	-$337,200
Total Operating Expenses	**$1,183,834**	**$1,505,113**	**$321,279**

Table 7.2.1 provides a snapshot of the projected operating expenses in the final year of the analysis (2051). It highlights the fact that maintenance savings in the Electrification case are significant, and utility costs will dominate the total operating expenses.

7.2.4 Cash Flow Profile

Figure 7.2.4 shows cumulative cash flow, combining utility, maintenance, and capital costs in 2024 dollars over 2024–2051. BAU exhibits a gradual cost increase, while electrification incurs sharp rises during conversion years (2028–2046) due to capital expenditures, followed by slower growth driven by electricity costs and lower maintenance.

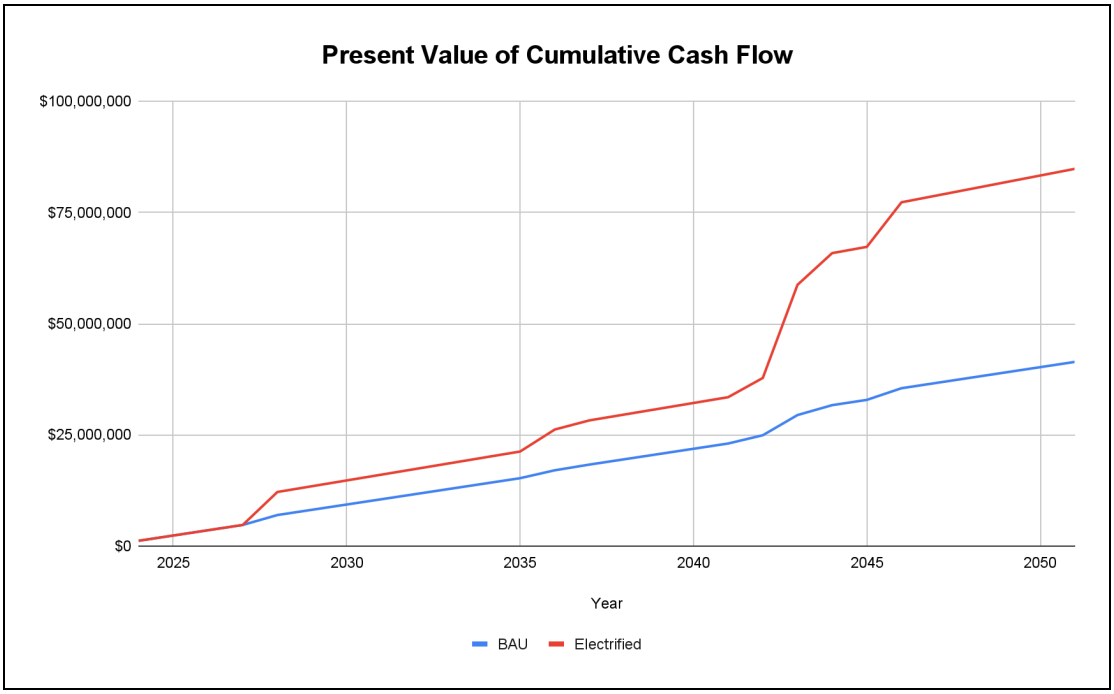


Figure 7.2.4 - Present Value of Cumulative Cash Flow

7.3 Summary of LCCA Findings

Electrification supports Chelmsford's decarbonization goals by reducing natural gas use and GHG emissions, as detailed in Section 6.4. However, it incurs a 28-year cost of $84.8 million compared to $41.4 million for BAU, a $43.4 million difference. Key drivers include high capital costs ($47.4 million vs. $8.3 million) for ASHPs, electrical upgrades, and retrofits, and higher electricity expenses ($20.8 million vs. $10.4 million). Electrification reduces natural gas costs ($4.0 million vs. $6.5 million) and maintenance expenses by $3.7 million due to lower servicing needs for electrified HVAC systems.

Cost estimates are preliminary, based on high-level assessments, not detailed engineering designs. Given the age of school buildings, detailed assessments are critical to refine costs, which could vary significantly. Utility-side upgrades (e.g., transformers) are excluded and require utility provider input post-design. State or federal incentives, not included, could offset electrification costs.

Conclusion

The Chelmsford Public School Building Electrification Roadmap Study provides a feasibility analysis of transitioning the town's nine public school buildings from fossil fuel-based systems to all-electric operations, aligning with the goal of carbon neutrality by 2050.

The Life Cycle Cost Analysis demonstrates that the Electrification case eliminates natural gas use and reduces greenhouse gas emissions, as detailed in Section 6.4, but incurs a 28-year cost of $84.8 million compared to $41.4 million for the Business-as-Usual case. This cost difference is driven by $47.4 million in upfront capital investments for all electric HVAC systems, electrical system upgrades, and building retrofits, alongside higher electricity expenses under currently estimated escalation rates. However, the Electrification case offers savings through the elimination of natural gas costs and a $3.7 million reduction in maintenance expenses over 28 years due to the lower servicing needs of electric systems.

The findings are based on high-level estimates, and several caveats apply. As noted in Section 6.5, detailed engineering assessments are essential to refine costs and implementation strategies, particularly given the age of the buildings, which may lead to significantly different final costs. Utility-side upgrades, such as transformers or service connections, are excluded from this analysis and require detailed designs for accurate costing by utility providers like National Grid. Potential state or federal incentives, which could offset initial investments, are also not included. This study equips the Town of Chelmsford with critical financial and technical insights to support its sustainability objectives, as outlined in the Massachusetts Green Communities Act and the town's Climate Leaders Roadmap.

APPENDIX

The Appendix provides supporting data and references for the electrification roadmap's analyses and cost estimates. The following tables detail life cycle costs, system cost estimations, and maintenance projections:

- **Life Cycle Cost Analysis – BAU Case**: Details 28-year (2024–2051) costs for the Business-as-Usual scenario, including utility, maintenance, and investment expenses.
- **Life Cycle Cost Analysis – Electrified Case**: Details 28-year costs for the electrified scenario, reflecting phased natural gas use until 2046.
- **Cost Estimation for Electrified Systems**: Summarizes direct costs for electrified HVAC systems, including ASHPs, DHW, piping, and switchgear for each facility.
- **Maintenance Cost Estimation for BAU and Electrified Case**: Compares annual maintenance costs, with assumptions for ASHPs, electric boilers, and HVAC components.

References:

- U.S. DOE Energy Escalation Rate Calculator, 2023.
- Johnson Controls, Measurement and Verification (M&V) Report, 2024.
- Town of Chelmsford Documentation
- U.S. National Renewable Energy Laboratory (NREL) Electrification Futures Studies. Available at: https://www.nrel.gov/analysis/electrification-futures

Life Cycle Cost Analysis - BAU Case

Year	Year #	Present Cost (PC) in 2024 $				Total Present Cost	Total Future Cost	Total Present Value
		Utility / Electric	Utility / Gas	Investments	Maintenance			
2024	1	$371,848	$231,986	$0	$580,000	$1,183,834	$1,183,834	$1,183,834
2025	2	$371,848	$231,986	$0	$580,000	$1,183,834	$1,215,402	$1,147,861
2026	3	$371,848	$231,986	$0	$580,000	$1,183,834	$1,247,813	$1,112,984
2027	4	$371,848	$231,986	$0	$580,000	$1,183,834	$1,281,092	$1,079,168
2028	5	$371,848	$231,986	$1,050,000	$580,000	$2,233,834	$2,487,892	$1,979,293
2029	6	$371,848	$231,986	$0	$580,000	$1,183,834	$1,350,342	$1,014,593
2030	7	$371,848	$231,986	$0	$580,000	$1,183,834	$1,386,362	$983,772
2031	8	$371,848	$231,986	$0	$580,000	$1,183,834	$1,423,345	$953,889
2032	9	$371,848	$231,986	$0	$580,000	$1,183,834	$1,461,317	$924,915
2033	10	$371,848	$231,986	$0	$580,000	$1,183,834	$1,500,305	$896,823
2034	11	$371,848	$231,986	$0	$580,000	$1,183,834	$1,540,336	$869,585
2035	12	$371,848	$231,986	$0	$580,000	$1,183,834	$1,581,438	$843,176
2036	13	$371,848	$231,986	$592,070	$580,000	$1,775,904	$2,448,328	$1,232,837
2037	14	$371,848	$231,986	$101,920	$580,000	$1,285,754	$1,812,908	$862,147
2038	15	$371,848	$231,986	$0	$580,000	$1,183,834	$1,711,459	$768,673
2039	16	$371,848	$231,986	$0	$580,000	$1,183,834	$1,757,139	$745,334
2040	17	$371,848	$231,986	$0	$580,000	$1,183,834	$1,804,041	$722,705
2041	18	$371,848	$231,986	$0	$580,000	$1,183,834	$1,852,199	$700,764
2042	19	$371,848	$231,986	$675,360	$580,000	$1,859,194	$3,011,871	$1,076,193
2043	20	$371,848	$231,986	$3,354,770	$580,000	$4,538,604	$7,621,747	$2,572,042
2044	21	$371,848	$231,986	$1,046,360	$580,000	$2,230,194	$3,822,332	$1,218,209
2045	22	$371,848	$231,986	$0	$580,000	$1,183,834	$2,058,067	$619,473
2046	23	$371,848	$231,986	$1,440,000	$580,000	$2,623,834	$4,756,717	$1,352,197
2047	24	$371,848	$231,986	$0	$580,000	$1,183,834	$2,169,452	$582,442
2048	25	$371,848	$231,986	$0	$580,000	$1,183,834	$2,227,391	$564,766
2049	26	$371,848	$231,986	$0	$580,000	$1,183,834	$2,286,881	$547,627
2050	27	$371,848	$231,986	$0	$580,000	$1,183,834	$2,347,965	$531,010
2051	28	$371,848	$231,986	$0	$580,000	$1,183,834	$2,410,683	$514,898
28 Year Total		**$10,411,733**	**$6,495,613**	**$8,260,480**	**$16,240,000**	**$41,407,827**	**$61,758,658**	**$27,601,210**

Life Cycle Cost Analysis - Electrified Case

Year	Year #	Present Cost (PC) in 2024 $				Total Present Cost	Total Future Cost	Total Present Value
		Utility / Electric	Utility / Gas	Investments	Maintenance			
2024	1	$371,848	$231,986	$0	$580,000	$1,183,834	$1,183,834	$1,183,834
2025	2	$371,848	$231,986	$0	$580,000	$1,183,834	$1,215,402	$1,147,861
2026	3	$371,848	$231,986	$0	$580,000	$1,183,834	$1,247,813	$1,112,984
2027	4	$371,848	$231,986	$0	$580,000	$1,183,834	$1,281,092	$1,079,168
2028	5	$558,579	$206,333	$6,117,550	$534,893	$7,417,355	$8,274,608	$6,583,033
2029	6	$558,579	$206,333	$0	$534,893	$1,299,805	$1,480,659	$1,112,509
2030	7	$558,579	$206,333	$0	$534,893	$1,299,805	$1,519,753	$1,078,427
2031	8	$558,579	$206,333	$0	$534,893	$1,299,805	$1,559,881	$1,045,392
2032	9	$558,579	$206,333	$0	$534,893	$1,299,805	$1,601,072	$1,013,370
2033	10	$558,579	$206,333	$0	$534,893	$1,299,805	$1,643,353	$982,331
2034	11	$558,579	$206,333	$0	$534,893	$1,299,805	$1,686,754	$952,245
2035	12	$558,579	$206,333	$0	$534,893	$1,299,805	$1,731,305	$923,081
2036	13	$610,204	$180,889	$3,640,359	$514,993	$4,946,445	$6,854,751	$3,451,657
2037	14	$612,976	$176,979	$756,278	$513,283	$2,059,516	$2,909,949	$1,383,856
2038	15	$612,976	$176,979	$0	$513,283	$1,303,238	$1,875,168	$842,200
2039	16	$612,976	$176,979	$0	$513,283	$1,303,238	$1,924,567	$816,353
2040	17	$612,976	$176,979	$0	$513,283	$1,303,238	$1,975,272	$791,300
2041	18	$612,976	$176,979	$0	$513,283	$1,303,238	$2,027,316	$767,018
2042	19	$674,221	$165,430	$3,002,188	$484,490	$4,326,329	$7,045,896	$2,517,620
2043	20	$840,696	$78,554	$19,678,173	$341,404	$20,938,826	$35,303,626	$11,913,596
2044	21	$1,060,936	$46,158	$5,725,259	$300,376	$7,132,728	$12,283,625	$3,914,892
2045	22	$1,060,936	$46,158	$0	$300,376	$1,407,470	$2,397,498	$721,641
2046	23	$1,262,313	$0	$8,515,938	$242,800	$10,021,050	$18,253,309	$5,188,886
2047	24	$1,262,313	$0	$0	$242,800	$1,505,113	$2,685,728	$721,048
2048	25	$1,262,313	$0	$0	$242,800	$1,505,113	$2,754,246	$698,352
2049	26	$1,262,313	$0	$0	$242,800	$1,505,113	$2,824,515	$676,372
2050	27	$1,262,313	$0	$0	$242,800	$1,505,113	$2,896,581	$655,084
2051	28	$1,262,313	$0	$0	$242,800	$1,505,113	$2,970,489	$634,467
28 Year Total		**$20,841,773**	**$3,980,690**	**$47,435,744**	**$12,563,997**	**$84,822,204**	**$131,408,061**	**$53,908,577**

Electrified Option Maintenance Cost Summary

Building	Size (Sq. Ft.)	Cost
Chelmsford High School	285,882	$76,519
Byam Elementary School	67,536	$18,626
Chelmsford Community Education	37,100	$12,715
Harrington Elementary School	67,536	$19,726
McCarthy Middle School	144,000	$43,532
Parker Middle School	105,000	$28,617
Center Elementary School	49,595	$15,947
South Row Elementary School	59,207	$21,671
Central Administration Building	10,192	$5,447
TOTAL		**$242,800**

Assumptions

Item	Cost	Notes
ASHP (ton)	$50.00	
HVAC distribution components (ton)	$50.00	
Electric Boilers	$2,500.00	
Cost % for Misc Cost	30%	
BAU maintenance Cost	$580,000	provided by the town

Maintenance Cost Estimation

Building	Size	HVAC Tons	ASHP Cost	HVAC Distribution Cost	# Boilers	Boiler Cost	BAU Cost	Misc
Chelmsford High School	285,882	138.00	$6,900.00	$6,900.00	1	$2,500.00	$200,729	$60,219
Byam Elementary School	67,536	19.00	$950.00	$950.00	1	$2,500.00	$47,420	$14,226
Chelmsford Community Education	37,100	24.00	$1,200.00	$1,200.00	1	$2,500.00	$26,049	$7,815
Harrington Elementary School	67,536	30.00	$1,500.00	$1,500.00	1	$2,500.00	$47,420	$14,226
McCarthy Middle School	144,000	82.00	$4,100.00	$4,100.00	2	$5,000.00	$101,108	$30,332
Parker Middle School	105,000	40.00	$2,000.00	$2,000.00	1	$2,500.00	$73,725	$22,117
Center Elementary School	49,595	30.00	$1,500.00	$1,500.00	1	$2,500.00	$34,823	$10,447
South Row Elementary School	59,207	42.00	$2,100.00	$2,100.00	2	$5,000.00	$41,572	$12,471
Central Administration Building	10,192	8.00	$400.00	$400.00	1	$2,500.00	$7,156	$2,147
TOTAL	826,048						**$580,000**	

Cost for Heating and Cooling Systems

		ASHPs			Hot Water						
Building	**Sqft**	**Heating Tons**	**Cost**	**Installation**	**DHW thermal kW**	**Cost**	**installation**	**MISC HVAC**	**Piping Cost**	**Switch Gear**	**Total Direct**
Chelmsford High School	285,882	138.00	$345,000	$345,000	38.00	$9,500	$9,500	$100,000	$285,882	$2,858,820	**$3,953,702**
Byam Elementary School	67,536	19.00	$47,500	$47,500	12.00	$3,000	$3,000	$100,000	$67,536	$675,360	**$943,896**
Chelmsford Community Education	37,100	24.00	$60,000	$60,000	24.00	$6,000	$6,000	$100,000	$37,100	$371,000	**$640,100**
Harrington Elementary School	67,536	30.00	$75,000	$75,000	25.00	$6,250	$6,250	$100,000	$67,536	$675,360	**$1,005,396**
McCarthy Middle School	144,000	82.00	$205,000	$205,000	37.00	$9,250	$9,250	$100,000	$144,000	$1,440,000	**$2,112,500**
Parker Middle School	105,000	40.00	$100,000	$100,000	46.00	$11,500	$11,500	$100,000	$105,000	$1,050,000	**$1,478,000**
Center Elementary School	49,595	30.00	$75,000	$75,000	5.00	$1,250	$1,250	$100,000	$49,595	$495,950	**$798,045**
South Row Elementary School	59,207	42.00	$105,000	$105,000	3.00	$750	$750	$100,000	$59,207	$592,070	**$962,777**
Central Administration Building	10,192	8.00	$20,000	$20,000	3.00	$750	$750	$100,000	$10,192	$101,920	**$253,612**

Energy Plant Cost

			Contingencies						
		TOTAL Direct	design/estimating	Construction	General Conditio	Insurance	Permitting	Contractor Fee	**TOTAL**
Building	**Cost**		15%	10%	10%	3.75%	1%	10%	
Chelmsford High School	$5,920,669	$3,953,702	$593,055	$395,370	$395,370	$148,264	$39,537	$395,370	$5,920,669
Byam Elementary School	$469,588	$943,896	$141,584	$94,390	$94,390	$35,396	$9,439	$94,390	$469,588
Chelmsford Community Education	$318,450	$640,100	$96,015	$64,010	$64,010	$24,004	$6,401	$64,010	$318,450
Harrington Elementary School	$1,482,959	$1,005,396	$150,809	$100,540	$100,540	$37,702	$10,054	$100,540	$1,482,959
McCarthy Middle School	$3,115,938	$2,112,500	$316,875	$211,250	$211,250	$79,219	$21,125	$211,250	$3,115,938
Parker Middle School	$2,180,050	$1,478,000	$221,700	$147,800	$147,800	$55,425	$14,780	$147,800	$2,180,050
Center Elementary School	$1,177,116	$798,045	$119,707	$79,805	$79,805	$29,927	$7,980	$79,805	$1,177,116
South Row Elementary School	$1,420,096	$962,777	$144,417	$96,278	$96,278	$36,104	$9,628	$96,278	$1,420,096
Central Administration Building	$374,078	$253,612	$38,042	$25,361	$25,361	$9,510	$2,536	$25,361	$374,078