MSBA Heat Pump Study
Final Report

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Abbreviations

(k)Btu	(1000) British Thermal Unit
(k)W	(1000) Watts
AC	Air Conditioning
AEC	Alternative Energy Credit
AHU	Air Handling Unit
APS	Alternative Energy Portfolio Standard
ARP	Accelerated Repair Program
ASHP	Air-Source Heat Pump
BTU	British Thermal Unit
CAPEX	Capital Expenditure
CFM	Cubic Feet Per Minute
CHW	Chilled Water
CHWP	Chilled Water Pump
CHWS/R	Chilled Water Supply/Return
CMR	Code of Massachusetts Regulations
COP	Coefficient of Performance
CUH/UH	Cabinet Unit Heater/ Unit Heater
DOAS	Dedicated Outside Air System
DTS/R	Dual Temperature Supply/Return
DX	Direct Expansion
ES	Elementary School
FCU	Fan Coil Unit
FTR	Finned Tube Radiation
GHG	Greenhouse Gas
GSF	Gross Square Feet
GSHP	Ground Source Heat Pump
HDPE	High Density Polyethylene
HS	High School
HVAC	Heating, Ventilation, Air Conditioning
HW	Hot Water
HWP	Hot Water Pump
HWS/R	Hot Water Supply/Return
HX	Heat Exchanger
IRA	Inflation Reduction Act
ITC	Investment Tax Credit
LCCA	Life Cycle Cost Analysis
MA	Massachusetts
MAAB	Massachusetts Architectural Access Board
MEBC	Massachusetts Existing Building Code
MS	Middle School
MSBA	Massachusetts School Building Authority
MTCO2e	Metric Ton of CO2 Equivalent
NFPA	National Fire Protection Association

NG	Natural Gas
NIST	National Institute of Standards and Technology
NPV	Net Present Value
RTU	Rooftop [Air Handling] Unit
TES	Thermal Energy Storage
TMY3	Typical Meteorological Year (Weather Data)
V	Volts
VRF	Variable Refrigerant [System]
VS/VT	Vocational Technical High School
W	Watts
W/SF	Watts per Square Foot
WSHP	Water Source Heat Pump

Executive Summary

The Massachusetts School Building Authority (MSBA) Heat pump study has been completed to facilitate schools moving toward Massachusetts' goal for net-zero carbon emissions by 2050. The heat pump study worked to inform the development of a program for conversion of heating and cooling systems of public schools in the Commonwealth of Massachusetts to heat pump systems. The goal of this study was to determine approximate scope, schedule, and cost factors related to converting buildings to heat pump systems.

Along with MSBA, Salas O'Brien selected 18 public K-12 schools to evaluate, utilizing the data from the 2016 School Survey completed by MSBA. The approach included selecting schools based on eight (8) priority categorizations with a similar allocation to the greater commonwealth. These typologies included School Type, Age of Building, Building Size, Fuel Source, HVAC Distribution Type, Cooling Distribution, Roof Area to Site Area Ratio, and the probability of electrical capacity for heat pump conversion. Once the schools were selected, data gathering and site visits were conducted to better understand the existing facilities.

Salas O'Brien analyzed the existing utility data from the 18 schools and utilized that data to develop energy models of the proposed heat pump conversions. Two (2) heat pump source technologies were evaluated, including ground source and air source. Multiple options within each technology category were evaluated based on the specific application. All options that were evaluated as part of this study included providing heating, cooling, and mechanical ventilation to all spaces within the schools, even if they currently did not have them. Preliminary concept narratives were utilized by a professional cost estimator to develop estimated project costs. The energy modeling alongside the projected total project costs were then utilized to develop a projected 30-year life cycle cost analysis and carbon emissions analysis.

The heat pump study indicates there is a large range of scope of work and associated costs that may be required for a district to convert their school to a heat pump-based system. The major levers impacting the anticipated costs for a heat pump conversion are related to the current HVAC systems. It is acknowledged that every school may not fall into one of these representative categories, and that many schools will associate with a combination of the categories, but the following represent some broad categorization of potential type of work required for a heat pump conversion, ordered from least amount of work to largest amount of work.

Existing systems mostly represented with distributed equipment and ventilation within occupied spaces:

1. Install Heat pump source equipment and connect into existing to remain HW & CHW systems.

2. Install heat pump source equipment, replace terminal equipment, and install new ventilation system.

3. Install heat pump source equipment, install new piping, and replace unit ventilators in kind.

4. Install heat pump source equipment, install new piping, replace terminal equipment, and install new ventilation system.

Existing systems mostly represented with centralized air handling equipment and duct distribution:

1. Install Heat pump source equipment and connect into existing to remain HW & CHW systems.
2. Replace select coils within existing to remain central air handling equipment with hot water and chilled water coils, or dual temperature coils.
3. Replace existing central air handling equipment with heating and cooling capable air handling equipment.
4. Replace existing central air handling equipment with heat pump-based equipment.

The potential solutions discussed within this report provide multiple different approaches to the above broad scopes of work with options for both ground source heat pumps and air source heat pumps. The costs for conversions do vary based on the type of heat pump and system approach; however, it was determined that the more significant factor on overall cost was related to the amount of work required within the building's distribution system, rather than the heat pump source. This is largely due to a focus on hybrid source approaches rather than limiting a solution to one source technology.

The summary and aggregation of data from the 18 analyzed schools is presented on a square foot basis where all costs are divided by the reported gross square footage of the school to allow a more even comparison and to help facilitate extrapolation to other schools. The results shown by this study indicate the average projected total project cost for a heat pump conversion as presented in this report is between $25/SF and $180/SF. While this is a significant range of costs presented in this report, there are some trends that can be seen from the building typologies selected.

There was no major correlation observed between the fuel source typologies. The roof to site acreage ratio was intended to provide some insight into the availability of land for a ground source system. However, as the main approach was a hybrid ground source system which optimized the size of the ground source, all analyzed schools appeared to have sufficient land area. However, in some cases, this would require drilling within a parking lot, playground, or sports field. It is expected that any districts interested in pursuing a ground source solution evaluate their specific land area further and determine if it is feasible to utilize alternatives for those end uses during the drilling and restoration duration.

The probability of electrical capacity for heat pump conversion was an interesting and useful metric, although it did not have a significant impact or correlation to the projected project costs. This is largely due to the schools that appear to require some electrical upgrades to support heat pump conversions also were the schools that required a significant amount of investment for a heat pump conversion. That, coupled with the electrical costs being a lower order of magnitude than the HVAC costs, led to no significant correlations. Approximately half of the schools evaluated are anticipated to require an electrical service upgrade to support a heat pump conversion.

As indicated in the generalized scopes of work, the largest correlation observed through this study was related to the existing HVAC systems, more specifically the existing cooling systems. There is some benefit from having a hot water system within the facilities, as it was assumed that the hot water system could be reused; however, it does not directly corelate to the overall expected cost as it is only half of the overall system. There is a reasonable correlation between the schools that have current chiller systems and the overall cost to convert. This is largely due to schools with chillers have chilled water infrastructure and cooling in the majority of the buildings. This leads to being able to reuse the existing terminal equipment and air handling equipment and limiting the scope of work to the mechanical rooms and heating and cooling generation equipment.

Ultimately, it was determined that schools with existing hydronic (water) based heating and cooling systems may require the least amount of work and therefore have a lower associated cost. This is a result of the assumption to leave much of the HVAC system in place and focus the conversion to the mechanical rooms and heating and cooling generation systems. This assumption requires that the existing equipment is in good working order and has sufficient useful life left. On the contrary, schools that currently do not have any cooling or hydronic distribution systems may require a more invasive scope of work and therefore a higher project cost.

The highest costs per square foot appear to occur in elementary schools, schools less than 70,000 GSF, and schools that are older than 60 years since the original opening date. However, this may not indicate a correlation to these typologies, but rather to the heating and cooling systems that typically appear in these types and sizes of schools. The elementary schools that were over 60 years old had a high probability of utilizing heating only unit ventilators as the primary heating and ventilation system. This type of school would require a larger scope of work to complete a heat pump conversion, especially with a new dedicated outdoor air system for ventilation. This provides some insight to while the elementary schools that are older than 60 years old and are less than 70,000 GSF may not individually indicate that a school would require a larger project cost to convert, they may indicate a higher probability of having heating only unit ventilator systems that would indicate a higher project cost.

Another interesting insight observed is that high schools tended to be larger footprints, which also tended to have a chiller-based cooling system. This is typical in the industry where larger facilities will tend to have chiller systems with a chilled water distribution. This indicates that larger high schools that currently have cooling may require a lower cost to convert as they have a higher probability of having a hydronic heating and cooling system. The overall decision to pursue a heat pump conversion should not solely be determined based on first project cost, and it is recommended that districts evaluate total project costs alongside life cycle costs, system advantages and disadvantages, and existing equipment conditions to determine the best conversion pathway.

The many available options for heat pump conversions presented in this report all advance the goal of reducing dependency on fossil fuels and the reduction of greenhouse gases. The results of the heat pump study clearly indicate that any and all heat pump conversions will significantly reduce the fossil fuel consumption and the associated greenhouse gas emissions over the next 30 years, contributing to a more sustainable future.

Purpose of Study

Chapter 208 of the Acts of 2004 established the Massachusetts School Building Authority (MSBA). Chapter 208 created a new program for school building construction, renovation, and repair projects (the “Program”), administered by the MSBA. The new program provides assistance to cities, towns, regional school districts, and independent agricultural and technical schools to finance school building projects. The MSBA has adopted regulations necessary to administer the Program and to review and approve applications for reimbursement for school building construction projects.

The MSBA historically has supported a program called the Accelerated Repair Program (ARP). The ARP focuses on the preservation of existing assets by performing energy-efficient and cost-saving upgrades, which will result in direct operational savings for school districts. The previous program included three (3) different types of repairs: boilers, windows, and roofs. The intent of this study is to inform a replacement to the boiler program with a heat pump program.

Salas O’Brien is providing Professional Engineering Services to the MSBA to evaluate existing public K-12 schools to assist in determining the scope, schedule, and cost factors involved in converting buildings to heat pumps for heating and cooling while removing dependency on fossil fuels. Additionally, Salas O’Brien is assisting the MSBA with developing programmatic processes to fund heat pump conversion projects within the ARP.

Heating, cooling, and powering the built environment accounts for 30% of the planet’s greenhouse gas emissions. The best way to electrify heating and cooling is to maximize the efficiency, or Coefficient of Performance (COP), of the mechanical equipment to minimize the cost per unit of thermal energy. One frequently used electrification technology is heat pumps. Figure 1shows the relationship between heat pump COP and cost, with the typical operational COP range called out for several different applications of heat pump technology. This graph shows that for heat pumps, the higher the efficiency, the lower the cost per unit of energy. It also shows that there are significant benefits to overall efficiency through the use of heat pumps versus electric boilers.

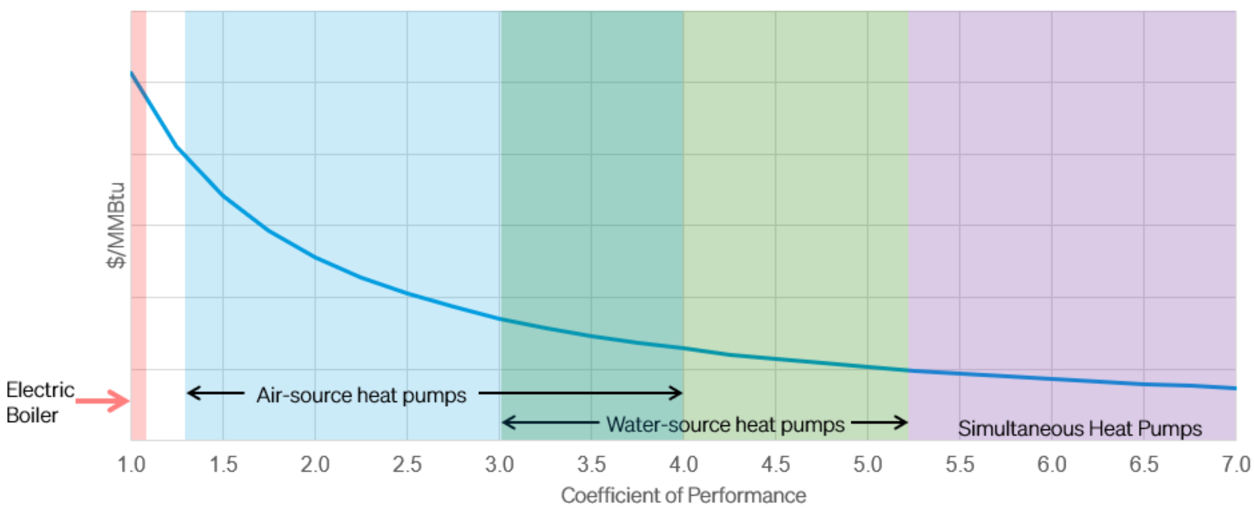


Figure 1 - Heat Pump COP vs Cost

Heat Pump Technology

The basis of this study is to utilize heat pump technology to convert school's thermal requirements from fossil fuel to electric driven systems. Heat pumps utilize a working fluid, a compressor, expansion valve, and heat exchangers to transfer thermal energy from a source to heat and cool buildings. There are many types and applications of heat pumps; however, this study focuses on ground source and air source heat pump technologies.

There are multiple types of ground source heat pump systems available to be installed; however, for the purpose of this study, it is assumed that all ground source systems will be vertical closed loop type. Other options include horizontal loop type and open loop type ground source. Further study would need to be conducted to determine if any alternatives would be viable options.

Closed loop ground source systems circulate fluid through a series of vertical boreholes. There are multiple types of boreholes designs possible, ranging from 400 to 1,500 feet. This study assumes an approximate depth of 850-foot-deep boreholes with a singular closed loop U-bend pipe within the bore. The other bore hole designs may be analyzed in a subsequent study or in the design phase of a future project.

These systems typically use water or an antifreeze solution such as propylene glycol or ethylene glycol as the heat transfer fluid. Closed loop system fluid never contacts the soil or groundwater. The heat transfer fluid is pumped through the vertical wells transferring thermal energy from the ground. The pipes within the vertical wells are then connected to horizontal pipe headers below the frost line and is then piped to the heat pumps.

Air source heat pumps utilize a similar process, except rather than transferring energy to and from the ground, they transfer energy to the air. Air source heat pumps extract heat from the outside air and transfer it indoors to provide heating during colder months. Conversely, during warmer months, they can reverse the process to cool indoor spaces by ejecting heat outside.

There are multiple types of air source heat pumps commercially available. These include air to water heat pumps where the system heats or cools a water loop that is then distributed throughout a facility, as well as air to air heat pumps where the system directly heats or cools air that is distributed throughout a facility. Another type is known as variable refrigerant flow (VRF) which can be either an air-to-air type or air-to-water type, with the difference being that many refrigerant pipes are run between pieces of equipment to transfer the energy throughout the building.

Simultaneous heat pumps reference utilizing a heat pump to produce both heating and cooling simultaneously rather than rejecting or absorbing heat to/from another source to produce either heating or cooling. This is typically useful in mild shoulder seasons such as spring and fall where energy can be transferred within the building. An example of this includes a classroom with east facing windows that may require some cooling in the morning due to the solar load, where the west facing may require some heating as it does not have the equivalent solar load.

Thermal Energy Storage (TES) is another tool that may be considered as a part of a heat pump solution. There are many types of TES options commercially available, such as water tanks and ice storage. These work by storing thermal energy to be dispatched at a later time. This can be especially useful to reduce the peak demand, either thermally or electrically. The overall quantity of thermal energy is not reduced using thermal energy storage; rather, it shifts the daily peaks so they are occurring at different times. TES may be used to reduce the peak demand on the overall electrical grid which can be advantageous, especially with any districts that have a peak demand-based rate structure. Another benefit of TES is to increase the efficiency curve of the heat pumps, allowing the heat pumps to run longer within their more efficient operational points. This also may be accomplished through the use of buffer tanks, which typically are smaller than a TES solution but provide a tank to increase the volume of a system, helping with the operation of the heat pumps.

There are many factors that contribute to the proper implementation of a heat pump solution, and it is anticipated that each project will evaluate the best implementation components for that application.

School Selection Methodology

The Massachusetts School Building Authority (MSBA) provides capital improvement projects funding for approximately 1,695 schools across Massachusetts. Salas O'Brien and the MSBA have assembled a set of 18 representative schools to help develop a heat pump replacement program that the schools may apply to.

In 2016, the MSBA completed a School Survey of approximately 1,497 buildings. This data was utilized to develop criteria in which the representative schools could be selected. Salas O'Brien analyzed the data provided within that survey and evaluated distribution across each of the categories.

Salas O'Brien then attempted to develop a representative data set by utilizing the eight priority categories and how they are distributed across the 1,495 schools from the last School Survey, on a percentage basis. The data set was developed to have a similar percentage of each individual option within the categories.

The school selection was randomized to begin, then individual schools were swapped out to fill a need in certain category percentages. Salas O'Brien attempted to maintain a random approach by filtering based on categories that were needed to create the corresponding percentage distribution and then utilizing a random selection from that subset.

In addition to the randomized approach, the MSBA provided recommendations for certain districts and schools that had expressed interest in being a part of the heat pump program. These schools were then included when possible if they fit within the desired data distribution.

The chosen schools are not meant to represent a list of schools that are imminent for consideration nor only those ideal for conversion to heat pumps. It is meant to be a list that represents a wide variety of schools of various ages, sizes, types of existing HVAC systems, etc., that may want to consider conversion to heat pumps at some point in the future. Through this broad evaluation of school typologies, the goal is to inform MSBA and future district applicants of the potential cost, time and space impacts that a heat pump conversion may have on existing facilities, particularly those that are most similar to the representative samples.

Building Typology Selection Criteria

Salas O'Brien evaluated a number of different categories of available data related to Massachusetts schools from the 2016 School Survey. Through discussions with the MSBA, it was determined that eight (8) categories would be utilized as priority categories for the basis of the selection.

School Type

Data Source: 2016 School Survey

Data Precision: Distinct quantitative classifications of school type.

Why Important: Programing differences between school types.

Definitions:

- Elementary School:
  - A school for the first four to six grades, usually including kindergarten.
- Middle School:
  - A school intermediate between an elementary school and a high school, typically for children in the sixth, seventh, and eighth grades.
- High School:
  - A school that is typically comprised of grades 9 through 12, attended after primary school or middle school.
- Vocational School:
  - A school that is typically comprised of grades 9 through 12, designed to provide vocational education or technical skills required to complete the tasks of a particular and specific job.

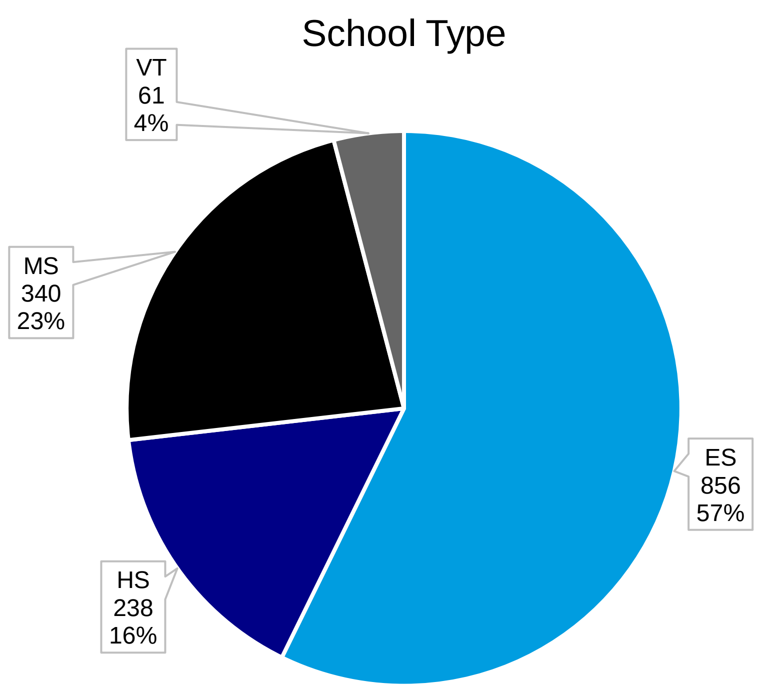


Figure 2

Age of Building (Opening Year)

Data Source: 2016 School Survey

Data Precision: Data includes the year opened only and does not represent any renovations.

Why Important: Age of construction may impact building loads and feasibility of heat pump retrofits.

Definitions:

- Over 60:
    - Building was originally built over 60 years ago (1956).
- 25 to 60:
    - Building was originally built between 25 and 60 years ago (1956-1991).
- 25 or less:
    - Building was originally built less than 25 years ago (1992-2016).

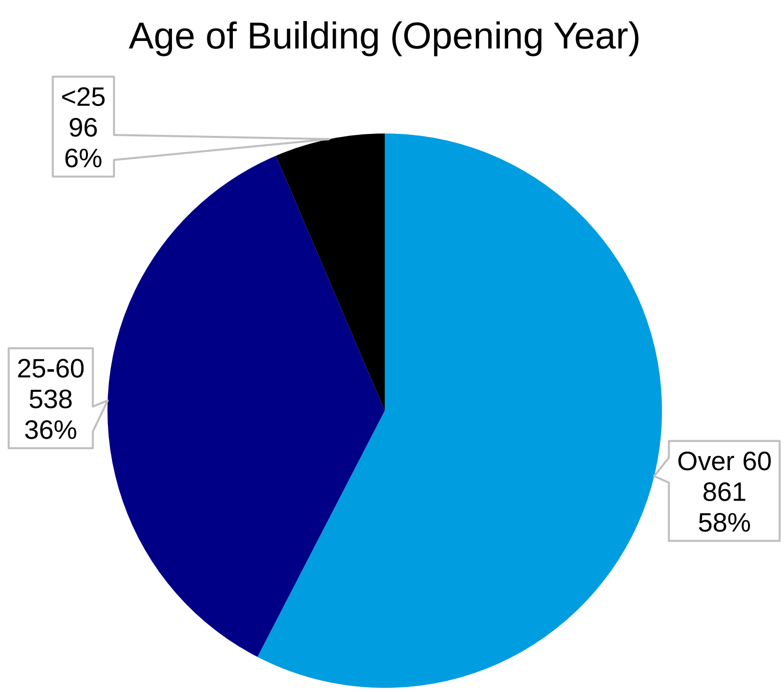


Figure 3

Building Size

Data Source: 2016 School Survey

Data Precision: Distinct quantitative data.

Why Important: Building layout and programming may differ between sizes of buildings impacting proposed retrofit solutions.

Definitions:

- 0 - 70,000 GSF
- 70,000 - 150,000 GSF
- >150,000 GSF

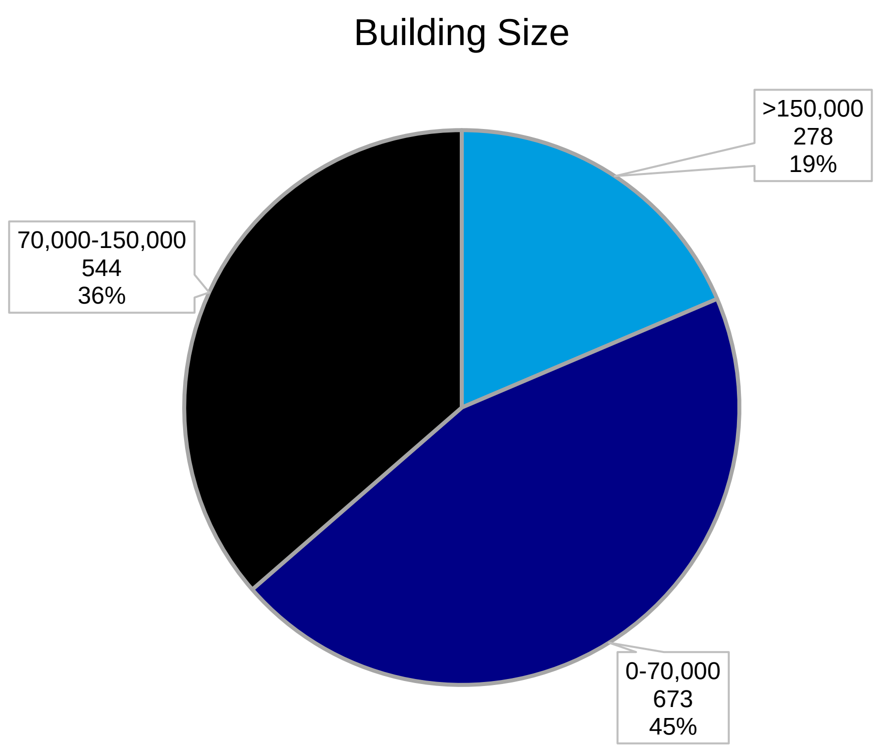


Figure 4

Fuel Source

Data Source: 2016 School Survey

Data Precision: Data collected as self-reported questions to the district. Distinct data options.

Why Important: Electric buildings may be decarbonization-ready and have the capacity for conversion to heat pumps. Fossil fuel source may indicate carbon emissions scale reduction.

Definitions:

- Gas/Propane:
  - Natural gas- or propane-based systems.
- Oil:
  - Fuel oil-based systems.
- Electric:
  - Fully electric-based systems.
- Dual:
  - Multiple fuel sources.

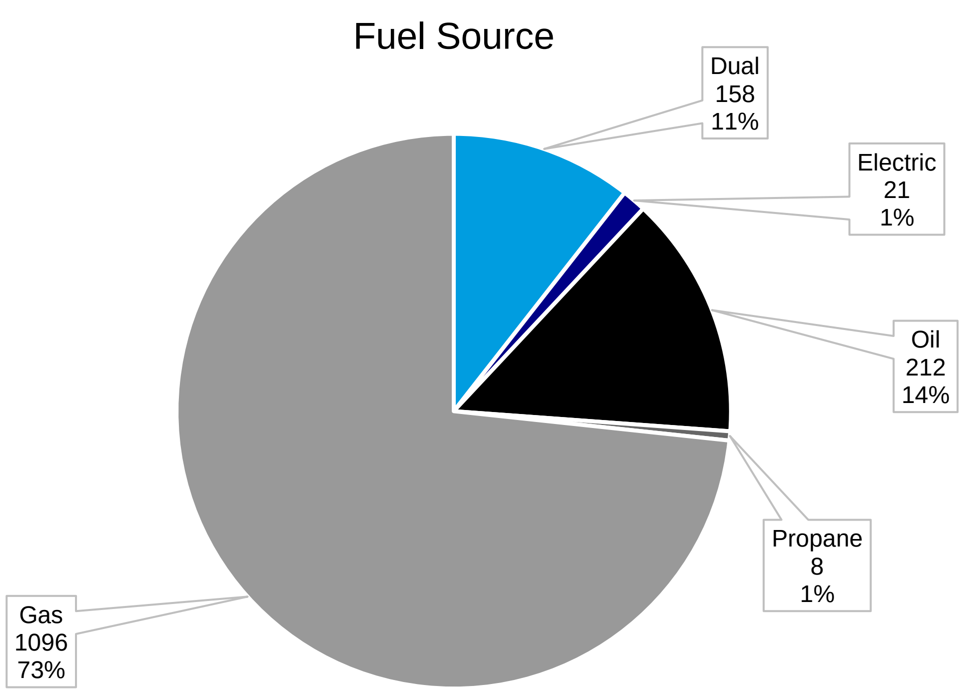


Figure 5

HVAC Distribution Type

Data Source: 2016 School Survey

Data Precision: Data collected as self-reported questions to the district. Data does not include any more detail. Data may be generalized and not fully representative of an entire building.

Why Important: Type of existing distribution will impact extent of potential invasiveness throughout building for compatibility with proposed heat pump solutions.

Definitions:

- Steam:
  - Steam is utilized for direct heat, assumed to be mostly steam radiation.
- Hot Water:
  - Hot water is utilized for heat, assumed to be mostly radiation.
- Forced Air:
  - May be direct gas-fired rooftop air-handling units, or hot water or steam coils within air-handling units. Assumed air-based systems provide heat.
- Heat Pump:
  - May include distributed water source heat pumps utilizing boiler and cooling tower or may include other types of heat pumps such as geothermal or air source.
- Other:
  - Unknown what the building systems are.

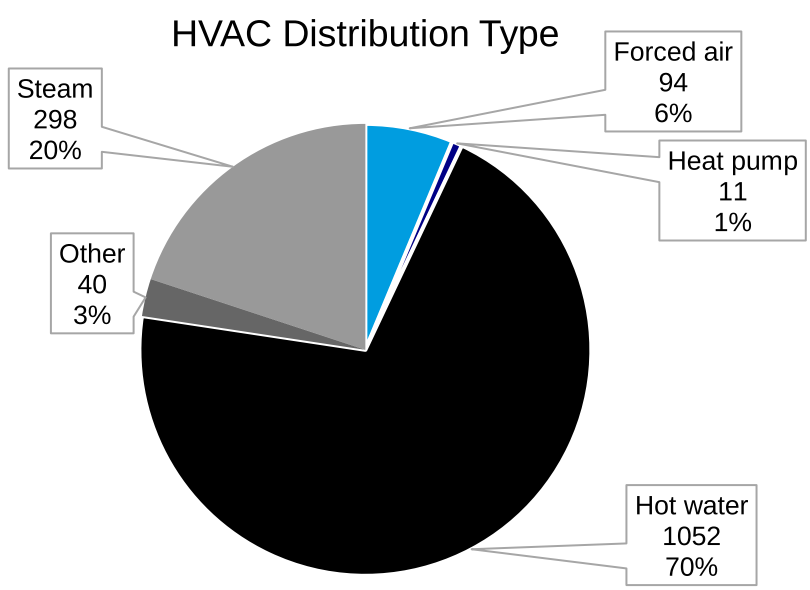


Figure 6

Cooling Distribution

Data Source: 2016 School Survey

Data Precision: Data collected as self-reported questions to the district. Data does not include any more detail. Data may be generalized and not fully representative of an entire building.

Why Important: Viability of heat pump projects will be dependent on what systems are currently installed and may require the replacement of those systems. Some heat pump solutions have significant benefits from having both heating and cooling requirements.

Definitions:

- None:
  - No cooling is currently present in the building.
- Direct Expansion (DX):
  - Cooling is provided through direct expansion, such as packaged rooftop air-handling units, Variable Refrigerant Flow (VRF) systems, mini splits, packaged terminal air conditioning units, or others.
- Chilled Water:
  - Cooling is provided through an air- or water-cooled chiller that produces chilled water and distributes it to either terminal units or central air-handling equipment.

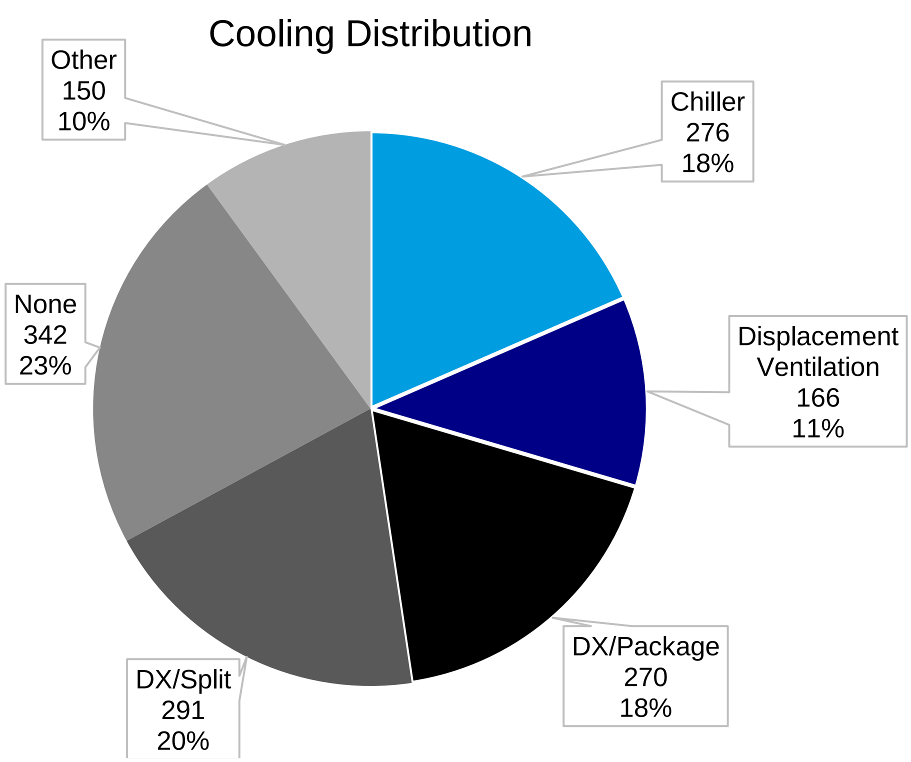


Figure 7

Roof Area to Site Acreage Ratio

Data Source: 2016 School Survey

Data Precision: Self-Reported by the district. Collected data utilized in a calculation.

Why Important: Heat pump solutions, including ground source, may be dependent upon available land.

Definitions:

- 0 - 3,500 Roof SF/Acre:
  - Building footprint divided by the parcel site acreage is less than 3,500.
- 3,500 - 7,500 Roof SF/Acre:
  - Building footprint divided by the parcel site acreage is between 3,500 and 7,500.
- 7,500+ Roof SF/Acre:
  - Building footprint divided by the parcel site acreage is greater than 7,500.
- Unknown:
  - Data was not available to complete the calculation.

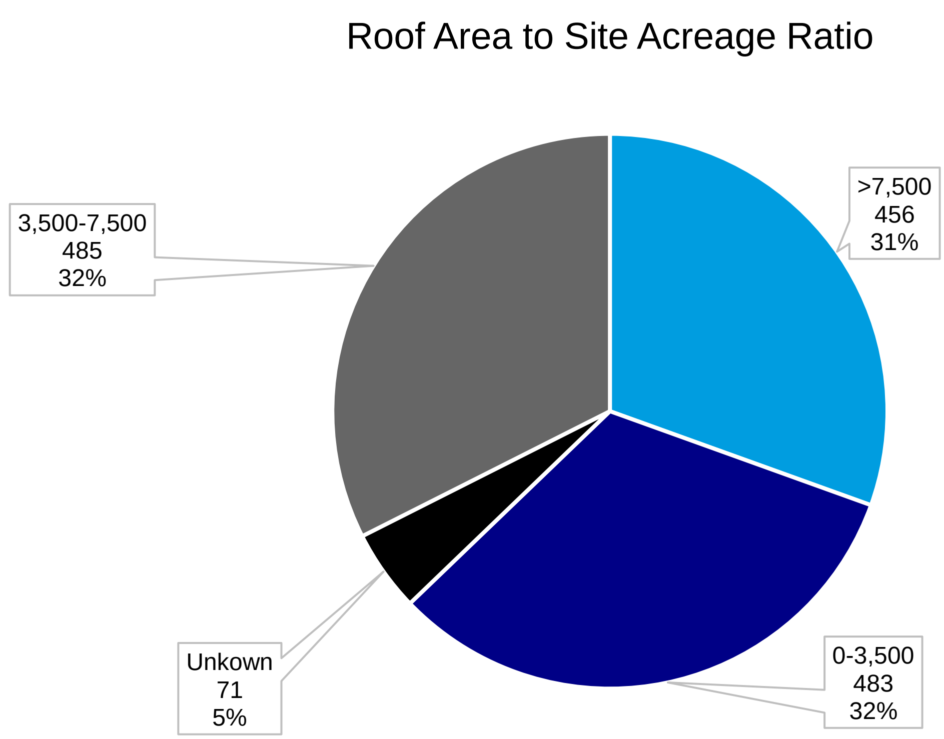


Figure 8

Probability of Electrical Capacity for Heat Pump Conversion

Data Source: 2016 School Survey. A combination of three (3) data fields were utilized to develop this category. These included amperage of the Main Breaker A, voltage of Main Breaker A, and HVAC air conditioning coverage. The amperage category listed a range of values, so the middle of the range was utilized for calculations. Salas O'Brien calculated an approximate wattage using the amperage and voltage and then divided this by the GSF to determine an approximate watts/SF of the existing electrical service. This coupled with the air conditioning coverage was utilized to develop the categorization.

Data Precision: Self-reported by the district. Collected data utilized in a calculation.

Why Important: Heat pump replacement may impact electrical service size and distribution and important to know existing condition and potential capacity for reuse.

Definitions:

- High probability of being "heat pump ready":
  - Building W/SF > 9 W/SF and building is fully or partially cooled.
- Medium probability of being "heat pump ready":
  - Building W/SF > 5 W/SF and <9 W/SF or >9 W/SF and not cooled.
- Low probability of being "heat pump ready":
  - Building W/SF < 5 W/SF.

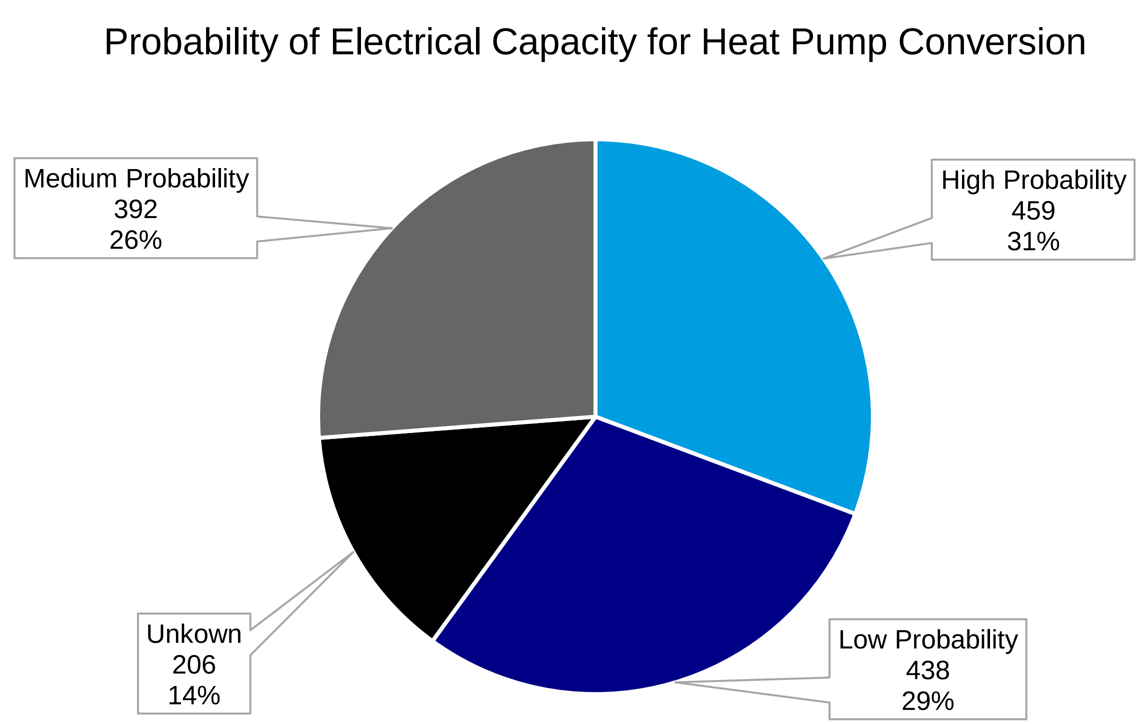


Figure 9

School List and Data – School Survey Data

The final selected school list is as follows:

1. William Monroe Trotter School, Boston, MA
2. Dean Luce Elementary School, Canton, MA
3. Hadley Elementary School, Hadley, MA
4. Maurice Donahue Elementary School, Holyoke, MA
5. Stoklosa Middle School, Lowell, MA
6. Lynn Classical High School, Lynn, MA
7. Ferryway Elementary School, Malden, MA
8. Greater New Bedford Regional Technical Vocational High School, New Bedford, MA
9. JFK Middle School, Northampton, MA
10. Oxford Middle School, Oxford, MA
11. Merrymount Elementary School, Quincy, MA
12. Seekonk High School, Seekonk, MA
13. Springfield High School of Science and Technology, Springfield, MA
14. Edmund Hatch Bennett Elementary School, Taunton, MA
15. Douglas MacArthur Elementary School, Waltham, MA
16. Southampton Road School, Westfield, MA
17. Nabnasset Elementary School, Westford, MA
18. Sullivan Middle School, Worcester, MA

The following table represents the eight (8) priority categories for school selection.

District	School Name	School Type	Age Of Building	Building GSF	Oldest Boiler Fuel Type	HVAC Heating Type	HVAC AC Type	Electrical Classi-fication	Roof/Site Acreage Ratio
Boston	William Monroe Trotter	MS	25-60	70,000-150,000	Gas	Hot water	Chiller	Medium Probability	>7,500
Canton	Dean S Luce	ES	Over 60	0-70,000	Dual	Hot water	Other	High Probability	3,500-7,500
Hadley	Hadley Elem	ES	25-60	0-70,000	Dual	Hot water	Other	Medium Probability	3,500-7,500
Holyoke	Maurice A Donahue Elem	MS	25-60	70,000-150,000	Electric	Other	Displacement Ventilation	High Probability	3,500-7,500
Lowell	Kathryn P. Stoklosa Middle School	MS	<25	70,000-150,000	Gas	Hot water	Chiller	High Probability	3,500-7,500
Lynn	Classical High	HS	25-60	>150,000	Gas	Hot water	Chiller	Low Probability	#N/A
Malden	Ferryway	MS	<25	70,000-150,000	Gas	Forced air	Chiller	High Probability	3,500-7,500
Greater New Bedford Regional Vocational Technical	Gr New Bedford Voc Tech	VT	25-60	>150,000	Dual	Steam	Chiller	#N/A	>7,500
Northampton	John F Kennedy Middle School	MS	25-60	70,000-150,000	Gas	Hot water	DX/Split	Medium Probability	0-3,500
Oxford	Oxford Middle	MS	25-60	70,000-150,000	Gas	Hot water	Other	Medium Probability	>7,500
Quincy	Merrymount	ES	Over 60	0-70,000	Gas	Steam	None	Low Probability	>7,500
Seekonk	Seekonk High	HS	25-60	70,000-150,000	Gas	Hot water	DX/Package	Medium Probability	0-3,500

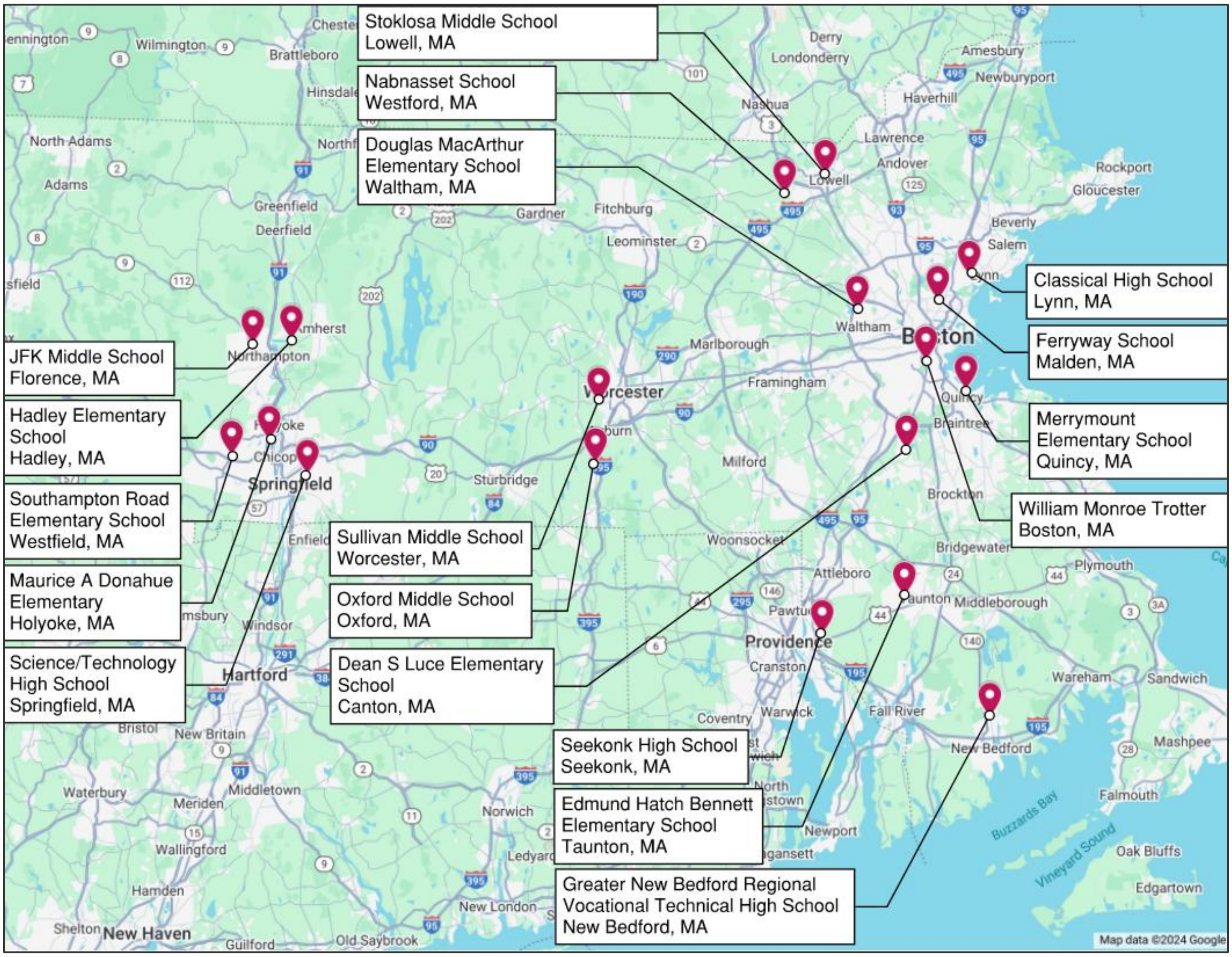
District	School Name	School Type	Age Of Building	Building GSF	Oldest Boiler Fuel Type	HVAC Heating Type	HVAC AC Type	Electrical Classi-fication	Roof/Site Acreage Ratio
Springfield	High School/ Science-Tech	HS	Over 60	>150,000	Gas	Steam	Chiller	Low Probability	3,500-7,500
Taunton	Edmund Hatch Bennett	ES	25-60	0-70,000	Electric	Other	Displacement Ventilation	Medium Probability	0-3,500
Waltham	Douglas MacArthur Elementary School	ES	<25	70,000-150,000	Gas	Forced air	Chiller	High Probability	0-3,500
Westfield	Southampton Road	ES	Over 60	0-70,000	Dual	Hot water	DX/Split	Low Probability	0-3,500
Westford	Nabnasset	ES	Over 60	0-70,000	Gas	Hot water	DX/Package	Low Probability	0-3,500
Worcester	Sullivan Middle	MS	25-60	>150,000	Gas	Hot water	Chiller	High Probability	0-3,500

The summary breakdown of each of the categories is:

School Type		Year Opened Classification		Building GSF		Oldest Boiler Fuel Type		HVAC Heating Type	
ES	7	<25	3	0-70,000	6	Dual	4	Forced Air	2
MS	7	25-60	10	70,000-150,000	8	Electric	2	Heat pump	0
HS	3	Over 60	5	>150,000	4	Gas	12	Hot water	11
VT	1					Oil	0	Other	2
						Other	0	Steam	3
						Propane	0		

HVAC Ventilation AC Type		Electrical classification		Roof to Site Acreage Ratio	
Chiller	8	High Probability	7	0-3,500	7
Displacement Ventilation	2	Medium Probability	5	3,500-7,500	6
DX/Package	2	Low Probability	5	>7,500	4
DX/Split	2				
None	1				
Other	3				

The following map represents the approximate location of the 18 visited schools across the Commonwealth of Massachusetts.



Data Gathering and Site Visit Approach

One of the primary objectives of this study was a discovery process in which the team gathered and reviewed information about each school. The team utilized information from numerous sources to establish an understanding of the mechanical systems, operations, and conditions around the facilities. Salas O'Brien developed a questionnaire and data request document that each district was requested to complete based on available data. An introductory meeting was completed in which the available information was discussed and districts provided preliminary insight into their facilities. Additional information was then obtained through visual observations, conversations with district personnel, and a limited review of the available existing documents. Representatives from Salas O'Brien, Code Red, and MSBA visited each site and observed the various mechanical and electrical systems described in this report.

In addition to information regarding the facilities and the associated systems, a critical portion of this analysis was completed using historical electric and fuel utility data for each of the facilities. The districts provided Salas O'Brien with between one (1) to five (5) years of historical data for use in this study.

The representatives that visited the individual schools conducted a limited review of the facilities including a high-level walkthrough and observation of the systems. The intent of the building review was to establish the main systems serving the facilities and not to document every independent system within a facility. In many facilities, representative rooms and systems were observed, and every space was not observed during the visit to limit the impact to ongoing teaching and learning.

The data and information presented herein may have been generalized and may not represent specific nuances or unique cases of individual facilities. The intent is to provide a set of representative case studies that may inform future heat pump projects through the ARP.

School List and Data – Post Site Visit Update

Throughout the data gathering and site visit phase of this study, it was determined that certain current systems within some facilities are different than those reported in the 2016 School Survey data. The following tables are Salas O'Brien's representation of the primary existing systems and priority categories.

District	School Name	School Type	Age of Building	Building GSF	Oldest Boiler Fuel Type	HVAC Heating Type	HVAC AC Type	Electrical Classif-ication	Roof/Site Acreage Ratio
Boston	William Monroe Trotter	MS	25-60	70,000-150,000	Gas	Hot water	None	Medium Probability	>7,500
Canton	Dean S Luce	ES	Over 60	0-70,000	Gas	Hot water	None	High Probability	3,500-7,500
Hadley	Hadley Elem	ES	25-60	0-70,000	Dual	Hot water	DX/Split	Medium Probability	3,500-7,500
Holyoke	Maurice A Donahue Elem	MS	25-60	70,000-150,000	Electric	Forced Air	None	High Probability	3,500-7,500
Lowell	Kathryn P. Stoklosa Middle School	MS	<25	70,000-150,000	Gas	Hot water	Chiller	High Probability	3,500-7,500
Lynn	Classical High	HS	25-60	>150,000	Gas	Hot water	Chiller	Low Probability	#N/A
Malden	Ferryway	MS	<25	70,000-150,000	Gas	Forced air	Chiller	High Probability	3,500-7,500
Greater New Bedford Regional Vocational Technical	Gr New Bedford Voc Tech	VT	25-60	>150,000	Dual	Hot Water	Chiller	#N/A	>7,500
Northampton	John F Kennedy Middle School	MS	25-60	70,000-150,000	Dual	Hot water	None	Medium Probability	0-3,500
Oxford	Oxford Middle	MS	25-60	70,000-150,000	Gas	Hot water	None	Medium Probability	>7,500
Quincy	Merrymount	ES	Over 60	0-70,000	Gas	Steam	None	Low Probability	>7,500

District	School Name	School Type	Age of Building	Building GSF	Oldest Boiler Fuel Type	HVAC Heating Type	HVAC AC Type	Electrical Classif-ication	Roof/Site Acreage Ratio
Seekonk	Seekonk High	HS	25-60	70,000-150,000	Gas	Hot water	DX/ Package	Medium Probability	0-3,500
Springfield	High School/ Science-Tech	HS	Over 60	>150,000	Gas	Hot Water	Chiller	Low Probability	3,500-7,500
Taunton	Edmund Hatch Bennett	ES	25-60	0-70,000	Electric	Forced Air	None	Medium Probability	0-3,500
Waltham	Douglas MacArthur Elementary School	ES	<25	70,000-150,000	Gas	Forced air	Chiller	High Probability	0-3,500
Westfield	Southampton Road	ES	Over 60	0-70,000	Dual	Hot water	None	Low Probability	0-3,500
Westford	Nabnasset	ES	Over 60	0-70,000	Gas	Hot water	None	Low Probability	0-3,500
Worcester	Sullivan Middle	MS	25-60	>150,000	Gas	Hot water	None	High Probability	0-3,500

School Type		Year Opened Classification		Building GSF		Oldest Boiler Fuel Type		HVAC Heating Type	
ES	7	<25	3	0-70,000	6	Dual	4	Forced Air	4
MS	7	25-60	10	70,000-150,000	8	Electric	2	Heat pump	0
HS	3	Over 60	5	>150,000	4	Gas	12	Hot water	13
VT	1					Oil	0	Other	0
						Other	0	Steam	1
						Propane	0		

HVAC Ventilation AC Type		Electrical classification		Roof to Site Acreage Ratio	
Chiller	6	High Probability	7	0-3,500	7
Displacement Ventilation	0	Medium Probability	5	3,500-7,500	6
DX/Package	1	Low Probability	5	>7,500	4
DX/Split	1				
None	10				
Other	0				

The comparison to the categories that changes between pre- and post site visit is as follows:

Oldest Boiler Fuel Type			HVAC Heating Type			HVAC Ventilation AC Type		
	Pre Visit	Post Visit		Pre Visit	Post Visit		Pre Visit	Post Visit
Dual	4	4	Forced Air	2	4	Chiller	8	6
Electric	2	2	Heat pump	0	0	Displacement Ventilation	2	0
Gas	12	12	Hot water	11	13	DX/Package	2	1
Oil	0	0	Other	2	0	DX/Split	2	1
Other	0	0	Steam	3	1	None	1	10
Propane	0	0				Other	3	0

School Analysis Summary

The following sections include the analysis of the 18 schools that have participated in this study. This section includes a brief explanation of each analysis section as well as any common information that will apply across all schools. The individual school sections are intended to be summaries, and additional detail is included in the appendix. The sections for each school include:

- Existing conditions summary
- Code Analysis
- Thermal Profile & Energy Analysis
- Proposed Solutions Analysis & Cost Estimating Narrative
- First Costs
- Life Cycle Cost Analysis

Existing Conditions Summary

This section explains the existing mechanical and electrical systems in each of the facilities based on the information provided by the districts and a limited site visit. This section is intended to provide a high-level overview of the major systems within a facility and not to document every system or piece of equipment. A color-coded floor plan of the major HVAC systems was developed based on the available information provided and through site investigations. This is intended to provide a general understanding of the types of systems and their general service area and may not include unique or singular conditions within the building. More detailed information including pictures of the equipment is included in the appendix.

Code Analysis

As part of the MSBA Heat Pump Study, Code Red Consultants provided fire protection, life safety, and accessibility code consulting services. The role of Code Red Consultants on the project was to provide high-level code considerations relative to the possibility of installing a heat pump system, and to assist with gathering building code-related data about each school. Through conversations with the project team, it was identified that the most important considerations center around identifying the thresholds requiring building-wide accessibility and sprinkler upgrades in a given building. Code Red Consultants participated in a site survey of each building. Our survey was intended to gather as much high-level information as possible while touring with the MEP team. The MEP team was otherwise focused mainly on existing boiler rooms and other heating and cooling related features of the schools. As such, Code Red Consultants did not independently survey all parts of any of the buildings, and the information and analysis provided herein is based on surveys being high-level only.

Refer to the appendix for full Code report.

Applicable Codes

The referenced codes for the purposes of this study are as follows:

- **Building:** 780 CMR – Massachusetts State Building Code 10th Edition*, which is an amended version of the 2021 International Building Code (IBC). 780 CMR 34.00 – Massachusetts State Existing Building Code, which is an amended version of the 2021 International Existing Building Code (IEBC)
- **Fire**: 527 CMR 1.00 – Massachusetts Comprehensive Fire Safety Code, which is an amended version of the 2021 Edition of NFPA 1, Uniform Fire Code
- **Accessibility**: 521 CMR – Massachusetts Architectural Access Board (MAAB) Rules and Regulations

* Projects filing for permits on or after June 30, 2025, will be subject to compliance with the 10th Edition.

Code Compliance Thresholds & Considerations

General Existing Building Scoping

Portions of an existing building undergoing repair, alteration, addition, or a change of occupancy are subject to the requirements of the Massachusetts Existing Building Code (MEBC).

In general, existing materials and conditions can remain, provided they were installed in accordance with the code at the time of original installation and are not deemed a condition requiring remediation by an authority having jurisdiction (AHJ).

All new work in existing buildings is required to comply with materials and methods in accordance with 780 CMR, or the applicable code for new construction, unless otherwise specified by the MEBC (MEBC 702.6).

Alterations to an existing building or portion thereof are not permitted to reduce the level of safety currently provided within the building unless the portion altered complies with the requirements of 780 CMR for new construction (MEBC 701.2).

Where compliance with the requirements of the code for new construction is impractical due to construction difficulties or regulatory conflicts, compliance alternatives may be approved by the building official (MEBC 101.5.0). Any compliance alternatives being sought are required to be identified on the submittal documents (MEBC 104.11).

Sprinkler Coverage Triggers (Buildings Without Existing Sprinkler Protection)

The surveys performed by Code Red Consultants included observation as to whether or not the building was provided throughout with an automatic sprinkler system or not, which was also correlated to previous survey data.

If a school is not already provided with a sprinkler system, one would be required as part of the project as outlined below. There are two (2) different code sources that trigger sprinkler system installations: the MEBC and Massachusetts General Law (MGL) Chapter 148 Section 26G. A sprinkler system is required to be installed if triggered by either source.

Within the MEBC, if the work area exceeds 50% of the area on a given floor, the work area is required to be provided with sprinklers (MEBC 804.2.2).

Within the MGL, sprinkler protection is required to be installed if the scope of work is considered a 'major alteration' based on MGL Ch. 148 Sec. 28G. Sec. 26G requires every building or structure, including 'major alterations' thereto, which totals more than 7,500 gross square feet, to be protected throughout with an automatic sprinkler system.

The law does not implicitly define what constitutes a 'major alteration.' An advisory document published by the Sprinkler Appeals Board in 2009 expands upon the application of this MGL to existing buildings, i.e. what should constitute 'major alterations.' This document summarizes that an existing building is required to be protected with sprinklers where all of the following four (4) conditions are satisfied:

1. Building gross square footage is more than 7,500 SF;
2. Sufficient water and water pressure exist to serve the system;
3. The nature of work to the building is considered as "major", including any one or more of the following:
    a. The demolition or reconstruction of existing ceilings or installation of suspended ceilings;
    b. The removal and/or installation of sub flooring, not merely the installation or replacement of carpeting or finished flooring;
    c. The demolition and/or reconstruction or repositioning of walls, stairways, or doors; or
    d. The removal or relocation of a significant portion of the building's HVAC, plumbing, or electrical systems involving the penetration of walls, floors, or ceilings.
4. The scope of work is proportional to the cost/benefit of sprinkler installation. To evaluate whether this is satisfied, the advisory document lists either of the following as thresholds for requiring sprinkler protection (evaluated over a 5-year period):
    a. Work affects 33% or more of the total gross square footage; or
    b. Total cost of the work (excluding cost to install a sprinkler system) is equal to or greater than 33% of the assessed value of the building, as of the date of permit application.

The building information data in the Appendices summarize whether each school is sprinklered and, if not, what the 33% cost threshold would be based on the assessed value of the building. Based on the above criteria, the cost trigger is just one item that needs to be evaluated; however, it may essentially act as the determining factor given that (1) all schools are greater than 7,500 SF; (2) all schools are presumed to have 'sufficient water and water pressure' (although that should be confirmed on a case-by-case basis); and (3) the 'nature' of the work being 'major' (Item 3 above) is subject to interpretation and could conservatively be assumed to be true for all cases where a large MEP project such as a heat pump system installation occurs.

We recommend that this sprinkler evaluation be studied in more depth for any non-sprinklered school if a heat pump system is being seriously considered, potentially including discussions with the local fire marshal.

Accessibility Thresholds

521 CMR ("MAAB") is the state accessibility code, and it has thresholds for when accessibility upgrades are required to take place. Notably, there is a cost threshold above which the entire building is required to come into compliance with 521 CMR.

The following summarizes the scoping requirements of 521 CMR Section 3.3 for projects in existing buildings. The costs referred to in the scoping requirements below are cumulative for all projects to the building within a rolling 36-month period:

- If the work is less than $100,000, then only the work being performed is required to comply with 521 CMR.
- If the work costs more than $100,000 but is less than 30% of the full and fair cash value of the building, then in addition to the work being performed, the following accessible features are also required to be provided in the building:
    - Accessible entrance
    - Accessible toilet room
    - Accessible drinking fountain
    - Accessible public telephone (if provided)

Note that if all work occurring in the building is limited solely to mechanical, electrical, plumbing, or fire protection systems (which could be true for a heat pump project), and/or the abatement of hazardous materials, then the $100,000 threshold is increased to $500,000 (521 CMR 3.3.1b, Exception b).

- If the work costs more than 30% of the full and fair cash value of the building, then all public portions of the building are subject to the requirements of 521 CMR.

The 30% threshold is determined by dividing the full and fair cash value of the building (excluding land) by the assessment ratio determined by the Massachusetts Department of Revenue and multiplying by 0.3.

The Appendices to this report contain the full and fair cash value and 30% threshold for each school, as an indicator to assist with gauging whether a heat pump project may trip the 30% threshold and require full building upgrades.

Full accessibility audits of the buildings were not within the scope of this project and were not performed. Such audits would have to be performed separately, if deemed necessary. The building survey data in the Appendices focuses on key building elements relative to the $100,000 trigger, where such information or observations were able to be made.

Of note, this study only summarizes state code requirements and therefore 521 CMR; federal law (ADA) would also need to be considered as it relates to requisite accessibility upgrades. Typically, ADA requires that up to 20% of a project's budget be allocated to 'removing barriers' from buildings. This would also need to be studied separately on a case-by-case basis.

Building Construction

Construction Classification

The construction type classification of a building may be a pertinent item of information for building renovation projects, and as such, an effort was made as part of the surveys to attempt to identify the construction type of each building. The classification of each building can be found in the individual building survey data sheets compiled in the Appendices.

Height and Area

Presuming no change of occupancy as part of a heat pump renovation project, the buildings will not be required to be evaluated for their compliance with height and area requirements. If a Change of Occupancy does occur, this may be required to be further evaluated.

Fire-Resistance Rating of Building Elements

Any new or altered structural members are required to minimally maintain the construction type of the buildings (MEBC 701.2 & 801.4). Table 601 in 780 CMR indicates the minimum fire-resistance ratings required for the buildings.

Fire Protection Systems

Automatic Sprinkler Systems

For buildings that have existing sprinkler protection, compliance of the existing sprinkler systems is required to be maintained in accordance with NFPA 13 and 780 CMR. All new sprinkler components and any modifications to the existing sprinkler system are required to meet new construction requirements of NFPA 13, 780 CMR, and 527 CMR 1.00 relative to their installation.

Fire Extinguishers

Portable fire extinguisher coverage is required to be maintained throughout a building installed in accordance with NFPA 10 (780 CMR 906.1).

Fire Alarm and Detection Systems

All buildings were found to be equipped with various types of fire alarm and detection systems. Coverage of the existing fire alarm systems is required to be maintained in accordance with NFPA 72.

All new fire alarm devices and any modifications to the existing fire alarm system are required to meet new construction requirements of NFPA 72, 780 CMR, and 527 CMR 1.00 relative to their installation.

Standby/Emergency Power Systems

Regardless of the scope of work, alterations to the existing standby/ emergency power supply are not permitted to reduce the level of safety currently provided within the building unless the portion altered complies with the requirements of 780 CMR for new construction (MEBC 701.2).

Within the current codes, emergency power is required for the following building features (780 CMR 2702.2):

- Exit signage in accordance with 780 CMR Section 1013.6.3
- Means of egress illumination in accordance with 780 CMR Section 1008.3
- Fire alarm systems including automatic fire detection systems if applicable
- Emergency voice/alarm communication system

Standby power system is required for the following building features (780 CMR 2702.2):

- Emergency Responder Radio Coverage System

Emergency and standby power systems are required to be installed in accordance with 780 CMR, 527 CMR 12.00, NFPA 110, and NFPA 111. The source of emergency power is permitted to be provided by an on-site emergency generator or from battery backup.

Means of Egress

All buildings are required to be provided with means of egress in accordance with 780 CMR that are maintained in accordance with 527 CMR.

Existing means of egress within the buildings that have been maintained as originally designed and constructed are permitted to remain unless deemed hazardous by the building official (780 CMR 102.6.4). Alterations to the existing means of egress are required to comply with the code for new construction (MEBC 801.4).

Accessible means of egress are not required in existing buildings (780 CMR 1009.1(1)).

Code Analysis Summary

A summary of the major code thresholds for each of the schools is below.

District	School Name	Sprinklered	33% Sprinkler Threshold	30% MAAB Threshold
Boston	William Monroe Trotter*	No	*	*
Canton	Dean S Luce	Yes	N/A	$3,704,129
Hadley	Hadley Elem	No	$5,028,374	$4,968,750
Holyoke	Maurice A Donahue Elem	No	$4,044,117	$3,790,175
Lowell	Kathryn P. Stoklosa Middle School	Yes	N/A	$10,002,189
Lynn	Classical High	Yes	N/A	$28,224,253
Malden	Ferryway	Yes	N/A	$7,686,189
Greater New Bedford Regional Vocational Technical	Gr New Bedford Voc Tech	Partial	$24,931,401	$23,609,281
Northampton	John F Kennedy Middle School	No	$6,247,395	$6,041,968
Oxford	Oxford Middle	No	$2,366,595	$2,264,684
Quincy	Merrymount	No	$3,016,101	$2,886,221
Seekonk	Seekonk High	Yes	N/A	$6,003,402
Springfield	High School/ Science-Tech	Yes	N/A	$23,575,515
Taunton	Edmund Hatch Bennett	No	$4,594,062	$4,305,588
Waltham	Douglas MacArthur Elementary School	Yes	N/A	$2,184,469
Westfield	Southampton Road	No	$987,855	$945,316
Westford	Nabnasset	Yes	N/A	$2,813,273
Worcester	Sullivan Middle	Yes	N/A	$5,821,639

The 33% sprinkler threshold = Assessed building value (not including the land) x 0.33
The 30% MAAB threshold = Assessed building value (not including the land) ÷ EQV x 0.30
***Assessed value not provided by District (see Appendix)**

Thermal Profile & Energy Analysis

This section explains some of the key analysis tools that were used in this study including evaluating the existing utility data, creating the thermal profiles, and making energy modeling assumptions.

The existing utility data provided by the districts was used to create an energy model of the school's current operations. It includes a comprehensive look at each school facility's energy usage and systems if each facility were to maintain its current equipment and make no changes. The existing operations were used as the foundation for all project assessments and analysis, comparing the facility's current state to proposed heat pump conversion strategies. The model includes thermal profiles and energy models.

A thermal profile is used to identify heat pump conversion strategies and for sizing the capacity of alternative energy sources to serve heating, cooling, and ventilation systems. These profiles were created for each facility. Accuracy is important as it is the foundation of sizing system components including equipment, energy sources, and supporting contracts. The thermal profiles are fundamental drivers of the economic evaluations conducted to assess strategy options.

Examples of such options include using ground loop heat exchangers (GLHX), air source heat pumps, or other infrastructure components. In the case of a ground loop heat exchanger/ground source heat pump, if under sized, it would deplete the energy in a heating dominant facility. If oversized, it would increase the first cost and could make the project financially infeasible. The information provided below emphasizes the process as it relates to sizing GLHX (as an example) but is similarly applicable to other energy source strategies considered.

When evaluating heating and cooling systems, British Thermal Units (BTUs) are utilized to quantify a total amount of energy (heating or cooling). Similarly, BTU/hr are utilized to quantify the amount of energy added or removed within one (1) hour.

Two (2) key components of the thermal profile are the building thermal peaks and energy consumed:

- Heating and cooling peaks (BTU/hr). The heating and cooling peak loads dictate the size of the heating and cooling equipment needed to provide sufficient heating and cooling capacity during the peak design conditions of the year. This requires sufficiently sized equipment to transfer the peak BTUs per hour from the building to energy source/sinks (during cooling) and from source/sinks to the building(s) (during heating).
- Heating and cooling energy consumption (BTU). The total heating and cooling energy consumed dictates the size source/sinks (i.e., a ground loop heat exchanger, etc.) needed to store the BTUs in the cooling season that will be used later during the heating season.

The monthly building's thermal load characteristics will determine the following:

- Base simultaneous load. The minimum simultaneous heating and cooling load required year-round in the building.
- Instantaneous simultaneous load. The amount of simultaneous heating and cooling load required beyond the base simultaneous load at different times throughout the year, which is largest in the transitional seasons such as summer to fall or spring to summer.

- Unbalanced heating load. The amount of heating load required in the building in addition to the base simultaneous and instantaneous simultaneous heating and cooling loads. These BTUs will be supplied from energy source/sinks.
- Unbalanced cooling load. The amount of cooling load required in the building in addition to the base simultaneous and instantaneous simultaneous heating and cooling loads. The BTUs for this are deposited in the energy source/sinks.

The building thermal profile development is crucial for identifying different energy source technology options, as well as right size heating and cooling equipment for building solutions. This study is focusing on heat pump technologies, and there are multiple approaches to utilize different technologies that are evaluated throughout this report. However, there are two (2) main energy sources that are discussed in different applications. They include closed loop ground source heat pumps and air source heat pumps. This will be discussed further in the following building evaluations.

Energy Conservation Measures (ECMs)

This report focuses on modeling heat pump conversions based on existing and a modeled future energy consumption. This report does not explicitly take into account any energy reductions from energy conservation measures. However, it is highly recommended that facilities evaluate their current operations and implement energy conservation as possible. These can have significant benefit to the heat pump conversion in terms of sizing of equipment and overall thermal comfort of the occupants. The MSBA ARP windows and/or roof program would provide a benefit as an ECM if the insulation value were increased with the replacement. Some additional examples include lighting replacements, air sealing, energy recovery, and HVAC controls upgrades.

Normalized Utility Consumption

The individual energy analysis and thermal profiles for the schools can be found in the sections specific to the district. However, to summarize the general findings for the 18 schools, a normalization of the data was completed. Normalization of data is utilized to standardize the data to a common level. Salas O’Brien normalized the utility consumption data provided by the districts and monthly thermal profile by floor area (square feet). Dividing the utility consumption data by the school square footage allows a comparison of the data on a similar basis. This shows the differences between the schools which utilize gas for heating and those that use electricity for heating as well as those with cogeneration.

A separate chart is provided for electricity consumption in kilowatt hour (kWh) per year per square foot and fuel consumption in therms per year per square foot.

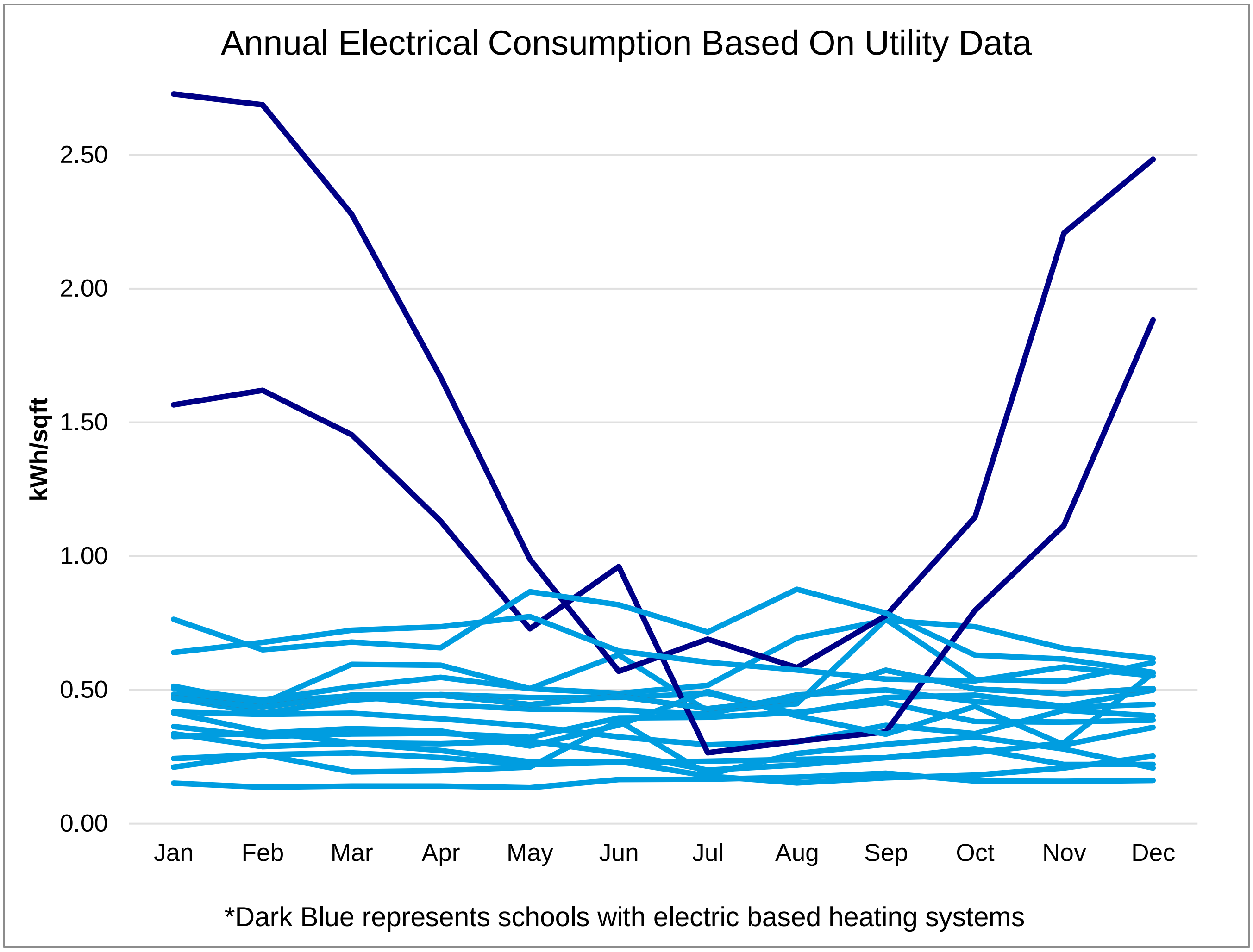


Figure 10 - Normalized Electrical Consumption kWh/sqft

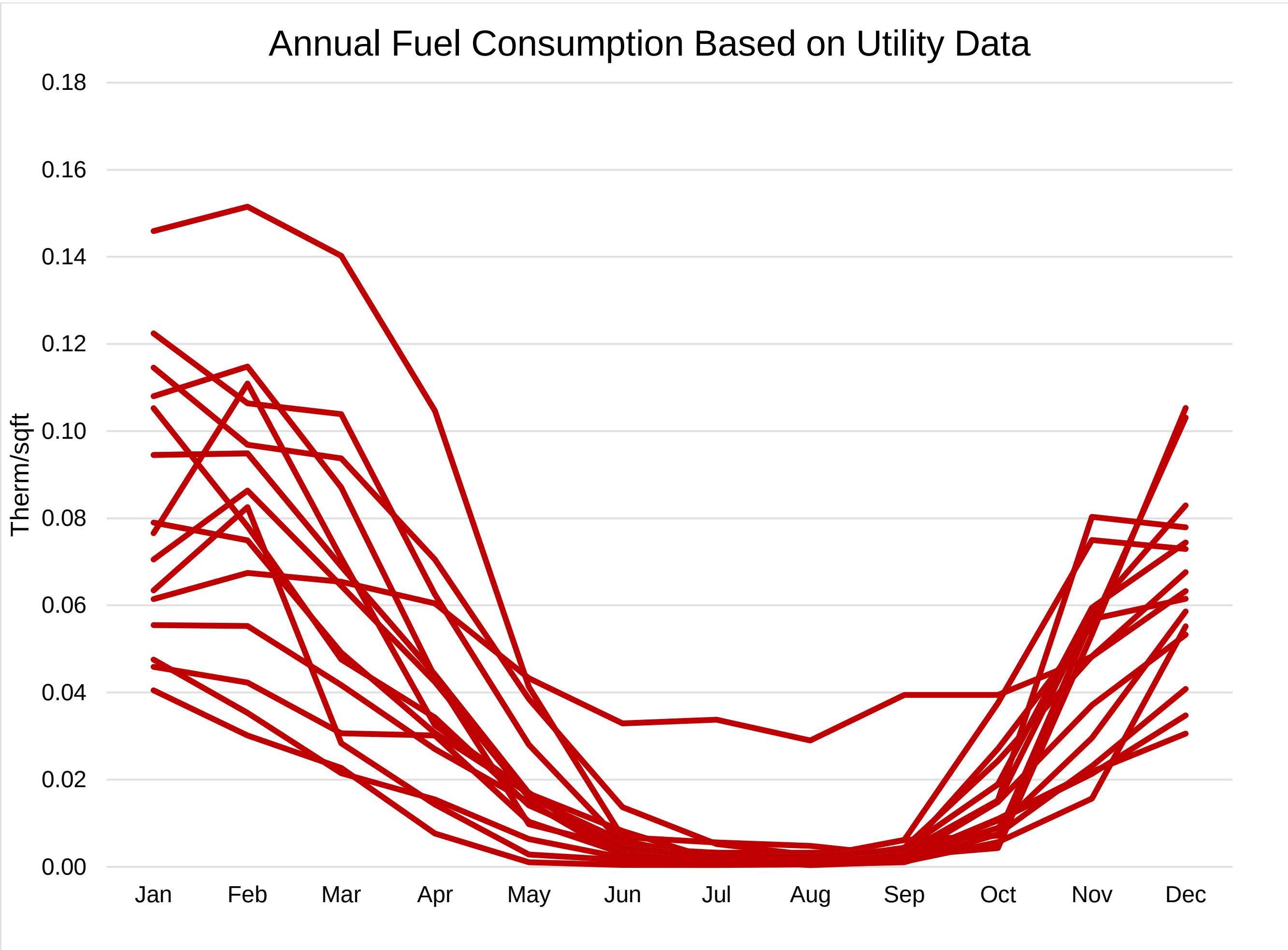


Figure 11 - Normalized Fuel Consumption Therms/sqft

Normalized Monthly Thermal Profile

The monthly thermal profile shows increased heating in the winter and cooling in the summer with some lower loads in the middle of the summer when the buildings are not occupied. The monthly thermal profiles represented in this chart include a modeled scenario where all facilities are 100% cooled. It can also be seen that there are many facilities where there is a drop in consumption in the summer months, which is typically seen due to a lower occupany and varying use from district to district. While there is a fairly wide spread of the annual heating loads, the 18 facilities follow very similar trends.

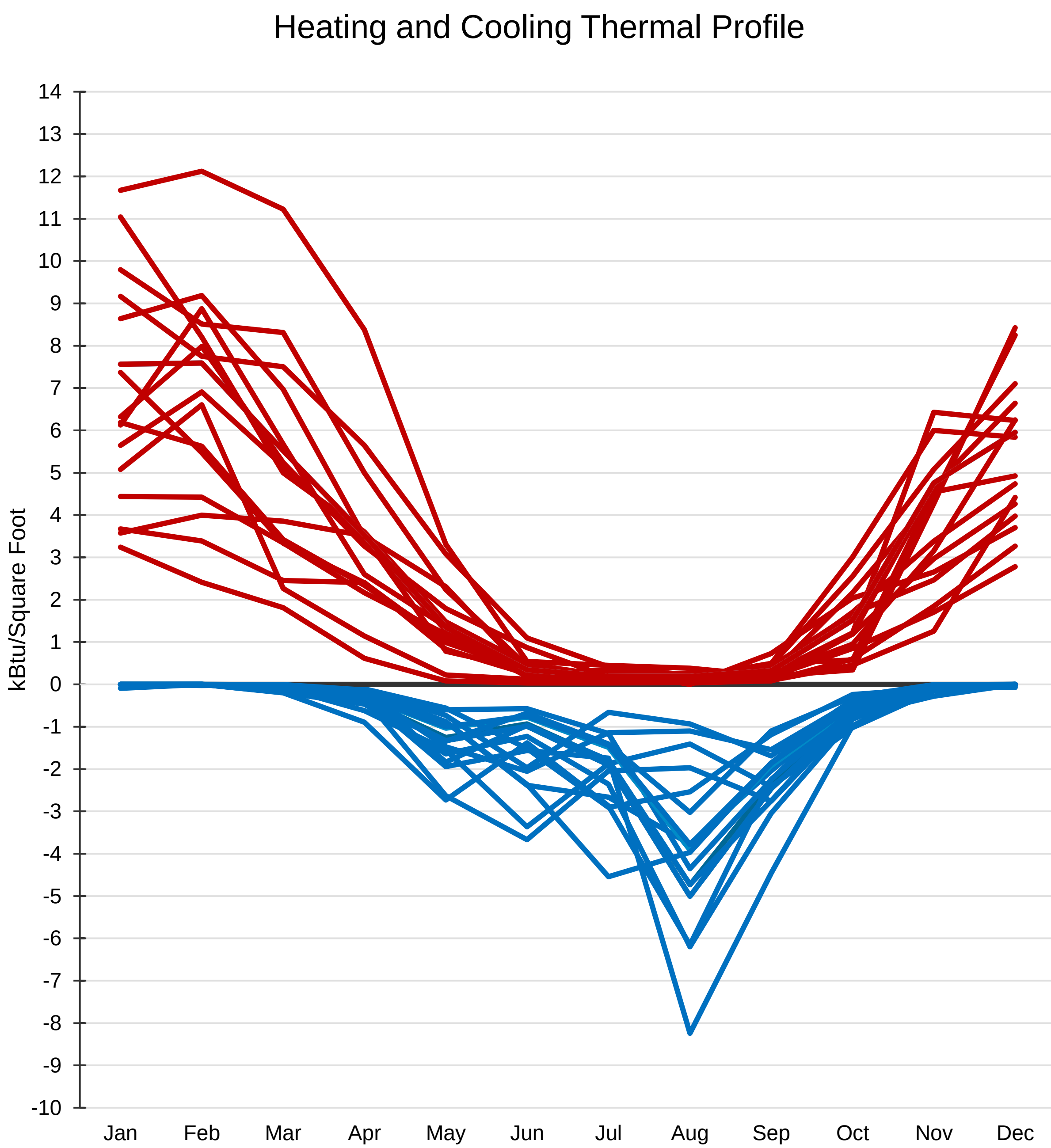


Figure 12 - Normalized Monthly Thermal Profile kBtu/sqft

Proposed Solutions Analysis & Cost Estimating Summary

As a part of the MSBA heat pump study, Salas O'Brien has been requested to provide conceptual heat pump conversion solutions and associated cost estimates for a representative 18 schools within the Commonwealth. The following representative schools are intended to provide an insight into potential requirements and options for a heat pump conversion of a similar type of facility.

This section explains some general conditions and assumptions that were made for all proposed solutions and the associated cost estimates. Furthermore, this section is intended to provide a general intent of the proposed solutions and is not intended to present all equipment and materials that will ultimately be required to serve the facility. Additional conceptual materials and methods are located in the appendix.

The intent of the proposed systems analyzed herein is to provide an approximation of what the minimum scope of work may be required to convert these schools to a heat pump based heating and cooling system. The intent is not to provide each facility with an entirely new mechanical, electrical, or plumbing system.

The intent of all proposed solutions is to provide updated mechanical systems that provide a bare minimum of the following for all classrooms and student spaces:

- Heating
- Cooling
- Mechanical Ventilation

Where it is feasible, multiple proposed solutions are provided for comparison purposes. Each solution will have benefits and negatives including but not limited to first costs, operating costs, construction duration, operational complexity, architectural modifications, etc. These are discussed in the summary portion of this report.

Many proposed heat pump system alternatives may include a hybrid approach where different mechanical systems are utilized to provide the best combination of energy output and capital cost. Where hybrid approaches are evaluated, an assumption was made based on the analysis presented in this report; however, during a future design phase, it may be determined that an alternative solution would better serve the facilities. The proposed system sizing presented in this analysis is preliminary and approximate and would be further developed during a feasibility/schematic design phase. In addition, there may be scenarios where a district may decide to integrate an existing or new fuel burning component (such as a new condensing boiler) to provide additional optimization and resilience. However, it is intended that in all scenarios, the heat pumps would be the primary source of heating and cooling.

The proposed solutions presented in this section are intended to represent potential options for heat pump conversions based on conceptual analysis of the available data and do not encompass every available option for heat pump conversions. The intent is to provide a range of solutions based on industry trends that may be applicable across the entire Commonwealth of Massachusetts. It is assumed a more detailed concept and feasibility analysis would be required for any district interested in completing a heat pump conversion, and these may include other variations of heat pump conversions that are not presented in this analysis.

Proposed Solutions Assumptions:

As part of the concept analysis for the heat pump conversions a number of assumptions and qualifications were made. These assumptions are described in this section and are included across all solutions where applicable to maintain consistency in proposed solution comparison. Sizes and capacities may vary from what is shown on drawings.

Building:

- The new equipment is intended to be incorporated into the existing spaces unless otherwise noted.
    - This may include existing boiler rooms, existing mechanical rooms, existing closets, or other available space within facilities.
- Any exterior equipment may be placed on roofs with the assumption that there is sufficient structural capacity available; otherwise, new equipment may be placed on grade. The exact location would be evaluated during a more detailed feasibility/schematic design.

Building:

- This study did not examine the potential for hazardous materials or any abatement that may be required as a part of construction within a school. It is highly recommended that any district conducts a detailed assessment of the school as part of a feasibility study to determine any remediation that may be required as a part of a heat pump conversion.

Geothermal:

- Geothermal bore fields are indicated in each individual solution. An assumed number and depth of bores are indicated. Vertical heat exchanger piping shall be installed within the wells and connected to lateral geothermal piping (GW). Refer to drawings for geothermal circuit piping schematic and vertical well detail.
- Bores shall be grouted with thermally enhanced graphite grout.
- Each bore field shall be provided with a geothermal circuit piping manifold. Size may vary from that shown on the drawings.
- Provide tracer wire system, including access points, on all High-Density Polyethylene (HDPE) piping.
- Existing parking lots, walks, curbs landscaping, and other surface improvements disturbed by installation of utilities and bore fields will need to be restored back to existing conditions.

Heating & Cooling Systems:

- An existing main mechanical room will be utilized in the building unless otherwise noted.
- Note that all options include cooling even if the associated building does not have cooling presently.
- The existing fuel fired equipment will be removed to provide space for new equipment unless noted otherwise.
- Deferred maintenance items are not included in the cost estimate except where a piece of equipment is required to be replaced in order to utilize the new system. An example of this is any equipment that is currently heating only would be replaced with equipment that can provide heating and cooling.

- In many instances, it is assumed that existing equipment such as pumps, piping distribution, air handling equipment, terminal equipment, ductwork, etc. are in sufficient working order and can be reused with the new proposed systems.
- The same type of control that is existing is included for equipment upgrades. Additional controls upgrades are not included.
  - If a building does not currently have a building management system, this study does not assume the implementation of a central control system.
  - If a space is currently controlled with a local thermostat and no building management system, it is assumed the new equipment would also be controlled with a local thermostat.
  - If a building has a full building management system, it is assumed the new equipment would be connected into the existing system.
  - There may be instances where an existing building management system cannot support new equipment without infrastructure upgrades. This additional scope may be covered by the contingencies included in this analysis.
- Many options include upgrades of the ventilation systems to dedicated outside air (DOAS) systems with full heating, cooling, and dehumidification control to provide a higher quality level of ventilation to the student spaces.
- Where existing facilities utilize unit ventilators for ventilation purposes, the preferred approach is to provide a new DOAS for ventilation purposes so that the unit ventilators are no longer the source of ventilation. However, a separate option is included for the replacement of the unit ventilators with new unit ventilators for cost comparison purposes.
- Where water is utilized as the main source of heat transfer fluid, the preferred approach is to install a 4-pipe HW & CHW system, and this is the main approach with facilities that currently have a hot water heating system only. However, in facilities that already have dual temperature piping systems or do not have any hydronic distribution, a 2-pipe dual temperature system is utilized.
- The general approach presented in many of these solutions includes a centralized heat pump approach where the generation equipment is largely located in mechanical rooms or outdoors. The intent is to reduce maintenance, noise, and disruption by reducing the number of compressors and keeping the compressors out of the student spaces. However, there are select solutions where a distributed heat pump solution may be more favorable. Distributed heat pumps may require additional electrical scope of work as well to provide additional power for the distributed compressors.

HVAC Equipment

- Where fan coil units (FCUs) indicated for proposed system conversions: All FCUs will have supply fan, hot water and chilled water coils, and modulating control valves to allow the spaces to maintain heating and cooling setpoints unless otherwise noted.
- Where unit ventilators are replaced for proposed system conversions: All unit ventilators will have supply fan, hot water and chilled water coils, and modulating control valves to allow the spaces to maintain heating and cooling setpoints.

- Where Air Handling Units (AHUs) or Rooftop Units (RTUs) are indicated for proposed system conversions: All AHUs will have supply fan array, chilled water coil, hot water preheat coil, return fan array, pre- and final filters, economizer, mixing box, and air blender unless otherwise noted.
- Where Dedicated Outside Air Systems (DOASs) are indicated for proposed system conversions: All AHUs will have supply fan array, chilled water coil, hot water preheat coil, return fan array, pre- and final filters, economizer, mixing box, and air blender.
- For all equipment, the following sizing assumptions were made:
  - Academic: 400 SF/Ton.
  - Air Handler Units & Coils: 1 CFM/SF
  - Dedicated Outside Air Systems & Coils: 0.5 CFM/SF

Electrical Systems

- As part of a heat pump conversion and electrification of the heating sources, it is anticipated that a new electrical service may be required to provide the required capacity.
- Approximations of an anticipated peak kW requirement were completed based on the available data and would need to be confirmed and further analyzed during a design phase.
- It is assumed that any utility-owned transformers that require additional capacity would be replaced and upsized by the utility company, and the costs are not included in this analysis.
- As part of this analysis, an option is included where a fossil fuel burning asset may be left in place as a peaking and redundancy asset running a small portion of the year. With this potential solution, it is assumed that the existing electrical service size would be sufficient, and the system would be correctly sized to stay within the limitations of the existing electrical service.
- For many solutions that include a full electrification of the heating system, it is assumed the main electrical switchboard would need to be replaced.
- For some facilities, preliminary analysis indicated that the existing electrical service size may be sufficient for a heat pump conversion; however, this would need to be validated during a design phase.
- Deferred maintenance items are not included in the cost estimate except where a piece of equipment is required to be replaced in order to utilize the new system.
- In all instances, it is assumed that existing equipment such as panelboards, branch distribution, wiring, etc. are in sufficient working order and can be reused with the new proposed systems.
- Another consideration related to the electrical capacity is the emergency situation where the school loses power. Maintaining a fossil fuel source may allow the school to operate with a smaller generator whereas a fully electric solution may require a much larger generator to be able to provide heat to the school. The costs associated with generator replacements or size increases are not included in this analysis as it is an individual district consideration of what level of backup generation is required at the school.

Plumbing Systems

- Due to the integration within an existing building, no additional plumbing spaces are required, and it is assumed all facilities will be from the associated building.

- Domestic hot water distribution for the building is assumed to remain. However, during a design phase, it may be evaluated to be included to be part of the new heat pump heating system.
- Where cooling is added, new condensate lines will be provided.

Fire Protection Systems

- As discussed in the code review section of this report, there are a number of facilities that do not currently have sprinkler systems installed. Depending on the final cost and scope of the heat pump projects, the facilities may require a sprinkler system to be installed as part of those projects. Refer to the code report and summary sections for more information on the exact sprinkler triggers.
- In facilities where sprinkler systems may be required to be added, the following is assumed.
    - The facility will be fully sprinklered.
    - The sprinkler systems will be wet.
    - The sprinkler system will meet or exceed NFPA 13 and any local jurisdiction requirements.
    - All areas with existing to remain ceiling and without ceilings will be protected by upright sprinkler heads.
    - Areas subject to freezing will be protected by dry pendant sprinklers connected to the wet system.
    - Special fire suppressions systems will be provided as appropriate, including dry chemical systems at kitchen hoods.
- For the purposes of this study, it is assumed there is sufficient water pressure available to feed a sprinkler system, and any additional building by building requirements such as fire pumps, standpipes, etc. would be an additional cost and are not included in this analysis.
- As part of the heat pump conversion evaluation and cost estimation analysis, a representative cost in $/GSF is provided.

Accessibility

- As discussed in the code review section of this report, depending on the final cost and scope of the heat pump projects, the facilities may require a full accessibility audit and any required alterations to be installed as part of the projects. Refer to the code report and summary sections for more information on the exact accessibility triggers.
- Due to the variability of accessibility scope that may be determined by a full accessibility audit, the costs are assumed to be part of the contingencies and not a separate line item.

Project Costs

Assumptions

A trade cost estimate was produced by Ellana Construction Consultants. This included estimating for mechanical and electrical scope of work based upon the proposed solutions narratives indicated in each of the individual district sections. The following represent the basis for pricing:

- Generally based on local prevailing union wage rates at the time the estimate was prepared.
- Contractor to have unrestricted access to work areas to schedule.
- Regular working hours with limited overtime.
- Pricing assumes a competitive bidding process, which is to mean multiple bids including all subcontractors and materials/equipment suppliers. If fewer bids are solicited or received, prices can be expected to be higher.
- Subcontractor's mark-ups have been included in each line-item unit price. Mark-ups cover the cost of field overhead, home office overhead, and subcontractor's profit. Subcontractor's mark-ups vary depending on market conditions.
- Quantification is based on measurable items where possible, for the remainder, parametric measurements used in conjunction with references from similar projects recently estimated by ELLANA.
- Additionally, for the facilities that may require an installation of a fire protection system per the code analysis section, a trade cost of $8.50/SF has been included.
- Due to the variability of accessibility scope that may be determined by a full accessibility audit, the costs are assumed to be part of the contingencies and not a separate line item.
- Hazardous Materials Abatement has been excluded from this estimate.

The following breakdowns have been utilized to capture the overall approximate total construction costs from the trade costs produced by the professional cost estimator.

Contingencies & Markups	
Project Requirements	4.0%
Design Contingency	15.0%
General Conditions	5.0%
Insurance	3.0%
Permit/Preconstruction	2.0%
Total Construction Cost Markup	**29.0%**

The total construction costs and the following soft costs breakdowns were then utilized to develop the approximate total project costs. Owner's contingency is considered for both unforeseen soft costs and change orders.

Soft Costs	
Project Management	4.0%
Owners Contingency	10.0%
Design Fee	10.0%
Total Soft Costs	**24.0%**

All costs utilized in the report are presented as total project costs and presented as net present value (NPV).

Contractor Availability

The majority of the proposed scope of work included in the heat pump solutions is comparable to typical HVAC and electrical scope that is completed in many schools across the Commonwealth. Therefore, the majority of the equipment replacement and related in-building ancillary work can be completed by many of the same mechanical and electrical workforce currently working with these School districts.

The specialized scope of work potentially required for these type of projects is related to the drilling of ground source bore holes, which as of the publishing of this report in spring of 2025, has a more limited pool of experienced vendor availability in the region. However, with the popularity of geothermal solutions on the incline, the market is responding with the number of qualified available drillers in the region increasing every year, leading to more competitive pricing and efficiency of operations. Should a District choose the ground source heat pump option for their school, it is generally assumed that each drill rig can complete approximately one (1) bore per day per rig with many contractors having multiple drill rig setups available when site conditions allow for it.

Rebates and Incentives

There are various incentives available at the state and federal level for energy efficiency and decarbonization projects in the form of rebates and tax incentives. These incentives are available to help offset the capital cost of these projects. At the time of publishing, there are several tax credit programs currently available that start to sunset in 2032 and go completely to zero in 2035. All incentives and rebates are preliminary and approximate and shall be evaluated and confirmed for eligibility and scale for each individual district and project. The incentives assessed for this project are as follows:

Alternative Energy Credits (AECs) for Heat Pumps in Massachusetts

Alternative Energy Credits (AECs) are part of Massachusetts' Alternative Energy Portfolio Standard (APS), which incentivizes the adoption of alternative energy technologies, including heat pumps. Heat pumps are recognized for their efficiency and ability to reduce greenhouse gas emissions, making them eligible for AECs.

Key Points about AECs for Heat Pumps:

- Eligibility: Heat pump systems, including air-source, ground-source, and water-source heat pumps, can earn AECs based on the amount of thermal energy they produce. This includes both residential and commercial installations.
- Calculation: AECs are awarded for every megawatt-hour equivalent (MWhe) of thermal energy generated by the heat pump system. The calculation considers the efficiency and performance of the heat pump.
- Incentives: By earning AECs, heat pump owners can receive financial incentives that help offset the initial installation costs. These credits can be sold or traded in the market, providing an additional revenue stream.
- Compliance: Retail electricity suppliers can purchase AECs to meet their APS compliance obligations, supporting the broader adoption of heat pump technology and contributing to the state's energy goals.
- Environmental Impact: Utilizing heat pumps reduces reliance on fossil fuels, lowers greenhouse gas emissions, and enhances energy efficiency, aligning with Massachusetts' commitment to achieving net-zero carbon emissions by 2050.

Mass Save Rebates

The Mass Save program in Massachusetts is designed to incentivize energy efficiency upgrades and renewable energy investments for residential and commercial properties. Through this program, eligible participants can receive financial incentives for making energy-efficient improvements to their facilities. The Mass Save program is administered by utility companies in partnership with the Massachusetts Department of Energy Resources (DOER). The current rebates included in this analysis are as follows.

- Ground Source Heat Pump: $4,500/Ton
- Air Source Heat Pump: $2,500/Ton

Investment Tax Credit

The Investment Tax Credit (ITC) for geo-exchange projects is a financial incentive provided by the Federal Government to promote the development and deployment of geo-exchange energy systems. The ITC allows eligible entities to claim a tax credit on their federal or state income taxes for a percentage of the cost of installing the geo-exchange energy system. Tax-exempt organizations, such as non-profits, municipalities, and certain educational or religious institutions, may also benefit from the ITC through a special provision called "direct pay" or through partnerships with tax-paying entities. In the case of direct pay, tax-exempt organizations can receive a cash refund equivalent to the value of the tax credit, helping to offset the costs of their geo-exchange system installation.

Social Cost of Carbon

Another critical financial consideration is the social cost of carbon. This metric represents the monetary value of the long-term damage caused by emitting one (1) ton of carbon dioxide, encompassing a range of factors such as health impacts, property damage from increased flood risk, and changes in agricultural productivity due to climate change. By quantifying these environmental and societal impacts, the social cost of carbon enables a more comprehensive comparison of decarbonization options.

In this analysis, carbon emissions are not assigned the social cost of carbon. However, it is an important consideration as decisions to pursue heat pump conversions are made. As of a 2023 report produced by the EPA, “Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances”, the social cost of carbon is estimated between $120-$340 per metric ton of CO2 equivalent (MTCO2e). The unit "CO2e" represents an amount of a Greenhouse Gas (GHG) whose atmospheric impact has been standardized to that of one unit mass of carbon dioxide (CO2), based on the global warming potential (GWP) of the gas.

An average school in 2025 has an emissions value of between 100-1,500 MTCO2e per year.

Important Note on Regulations and Incentives

This analysis was completed as of January 2025, and the financial projections reflect policy incentives available at that time. Given the evolving nature of federal, state, and local policies, financial assumptions may need to be revisited as regulations, incentives, and compliance requirements change. Shifts in government administrations and legislative priorities could impact the availability and structure of renewable energy incentives, emissions reduction policies, and utility regulations. However, renewable energy incentives have historically remained available across multiple administrations, with federal investment tax credits (ITCs) for renewables—including geothermal heat pumps—predating the Inflation Reduction Act (IRA) of 2022. These long-standing incentives demonstrate the durability of government support for clean energy investments, even as specific program details and funding mechanisms evolve over time.

All incentives and rebates are preliminary and approximate and shall be evaluated and confirmed for eligibility and scale for each individual district and project.

Summary

The individual project costs for the schools can be found in the sections specific to the district. However, to summarize the general findings for the 18 schools, the data was standardized to a common level by dividing the costs by the school square footage. In schools where certain proposed options were not applicable, they were not included in the cost exercise. Refer to the specific district section for more information.

Ground Source Heat Pump Total Project Costs

The following chart shows the approximate total project costs for the ground source heat pump solution with and without potential incentives.

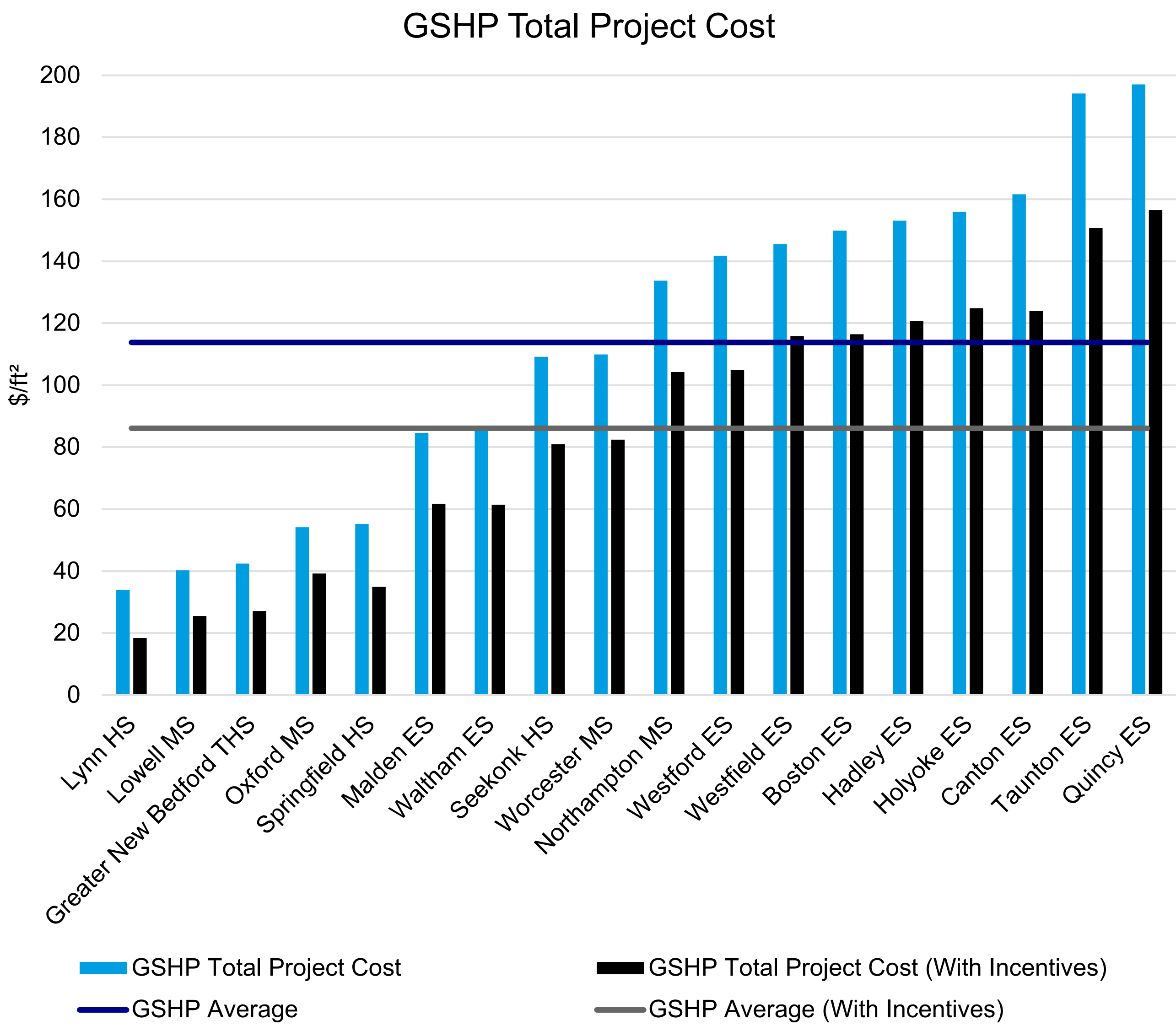


Figure 13

As discussed previously, there may be some benefits and considerations to include a fuel fired boiler as part of a hybrid ground source heat pump system. The following chart (with Boiler) shows the approximate total project costs for the ground source heat pump solution with a boiler with and without potential incentives. Buildings currently without a boiler (Lowell MS and Taunton ES) are excluded.

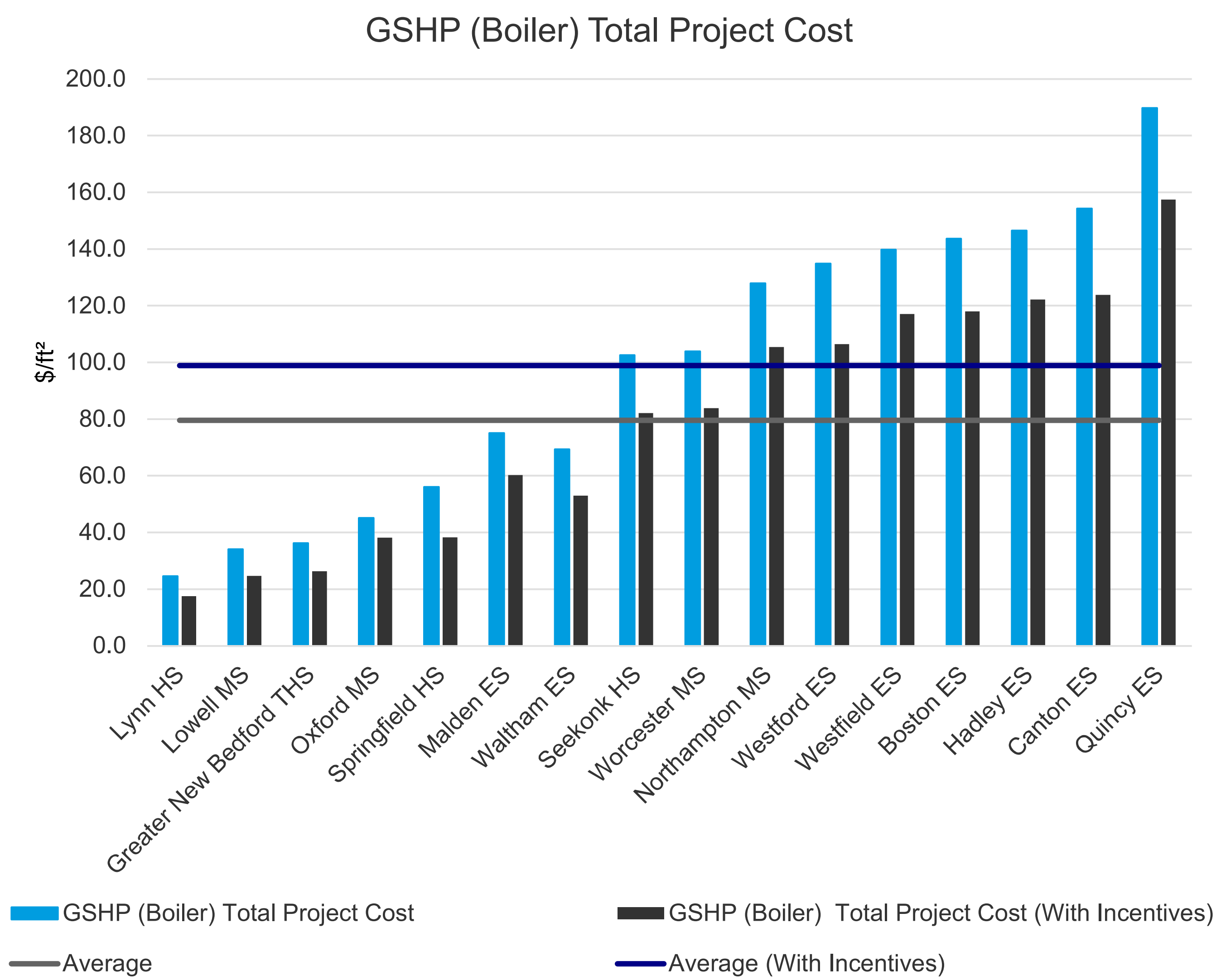

GSHP (Boiler) Total Project Cost
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
$/ft²
Lynn HS
Lowell MS
Greater New Bedford THS
Oxford MS
Springfield HS
Malden ES
Waltham ES
Seekonk HS
Worcester MS
Northampton MS
Westford ES
Westfield ES
Boston ES
Hadley ES
Canton ES
Quincy ES
GSHP (Boiler) Total Project Cost
GSHP (Boiler) Total Project Cost (With Incentives)
Average
Average (With Incentives)

Figure 14

The following chart shows a combination of the previous two charts, comparing the two GSHP options without incentives, to illustrate the potential projects savings when incorporating a fuel fired boiler as part of a hybrid ground source heat pump system, before potential incentives

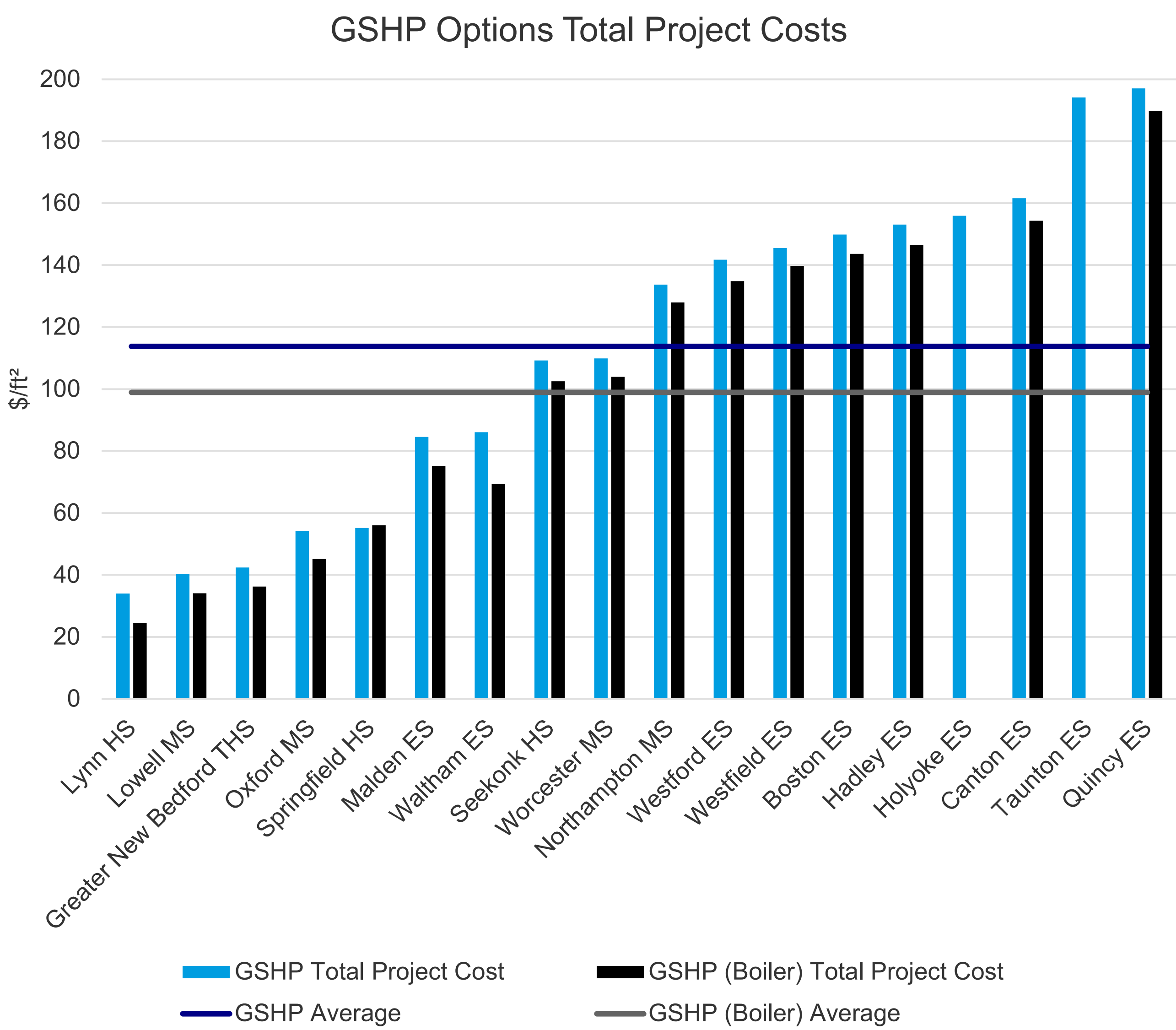


Figure 15

The following chart shows a combination of the previous two charts, comparing the two GSHP options with potential incentives, to illustrate the potential project savings, or not, when incorporating a fuel fired boiler as part of a hybrid ground source heat pump system, after potential incentives.

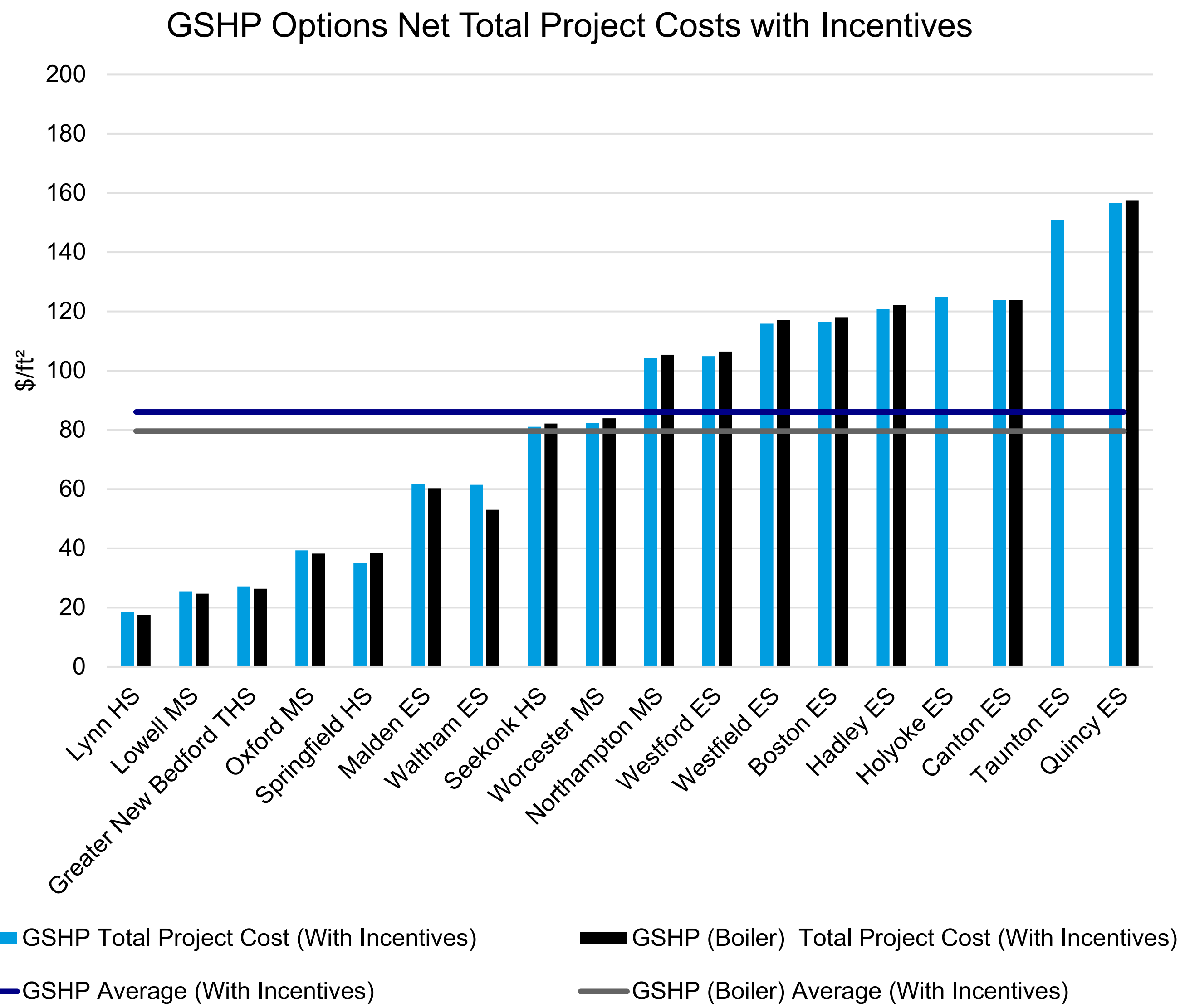


Figure 16

Air Source Heat Pump Project Costs

The following chart shows the approximate total project costs for the air source heat pump solution without incentives. The solutions that were evaluated were not feasible for every school; therefore, only the solutions that were feasible were included in the cost evaluation. For example, the unit ventilator solutions were only included for schools that currently have unit ventilators. Additionally, VRF was not included for schools that had a significant hydronic-based heating and/or cooling system because the proposed solutions utilized existing infrastructure where possible. Refer to the individual school sections for more information.

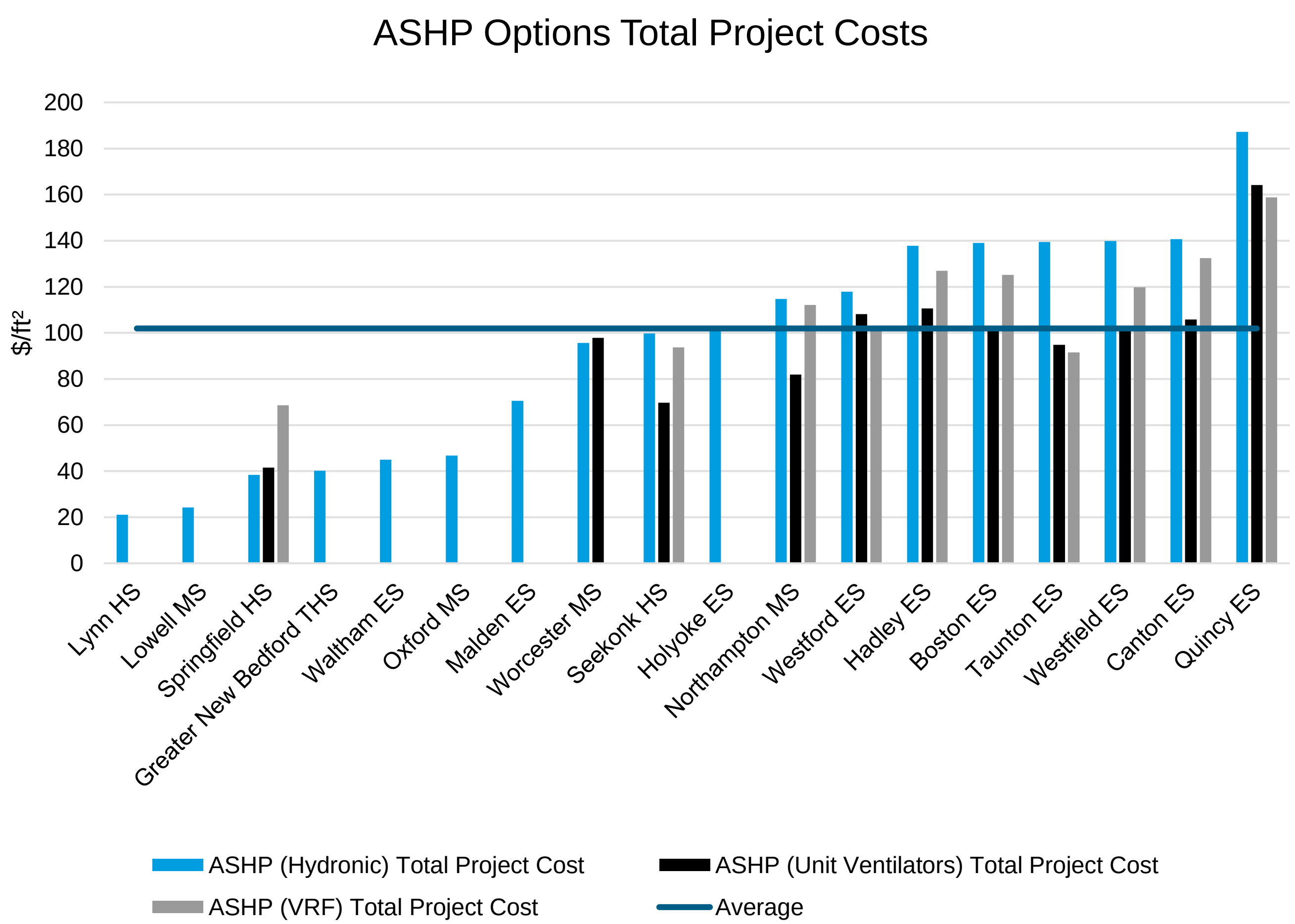


Figure 17

The following chart shows the approximate total project costs for the air source heat pump solution with potential incentives.

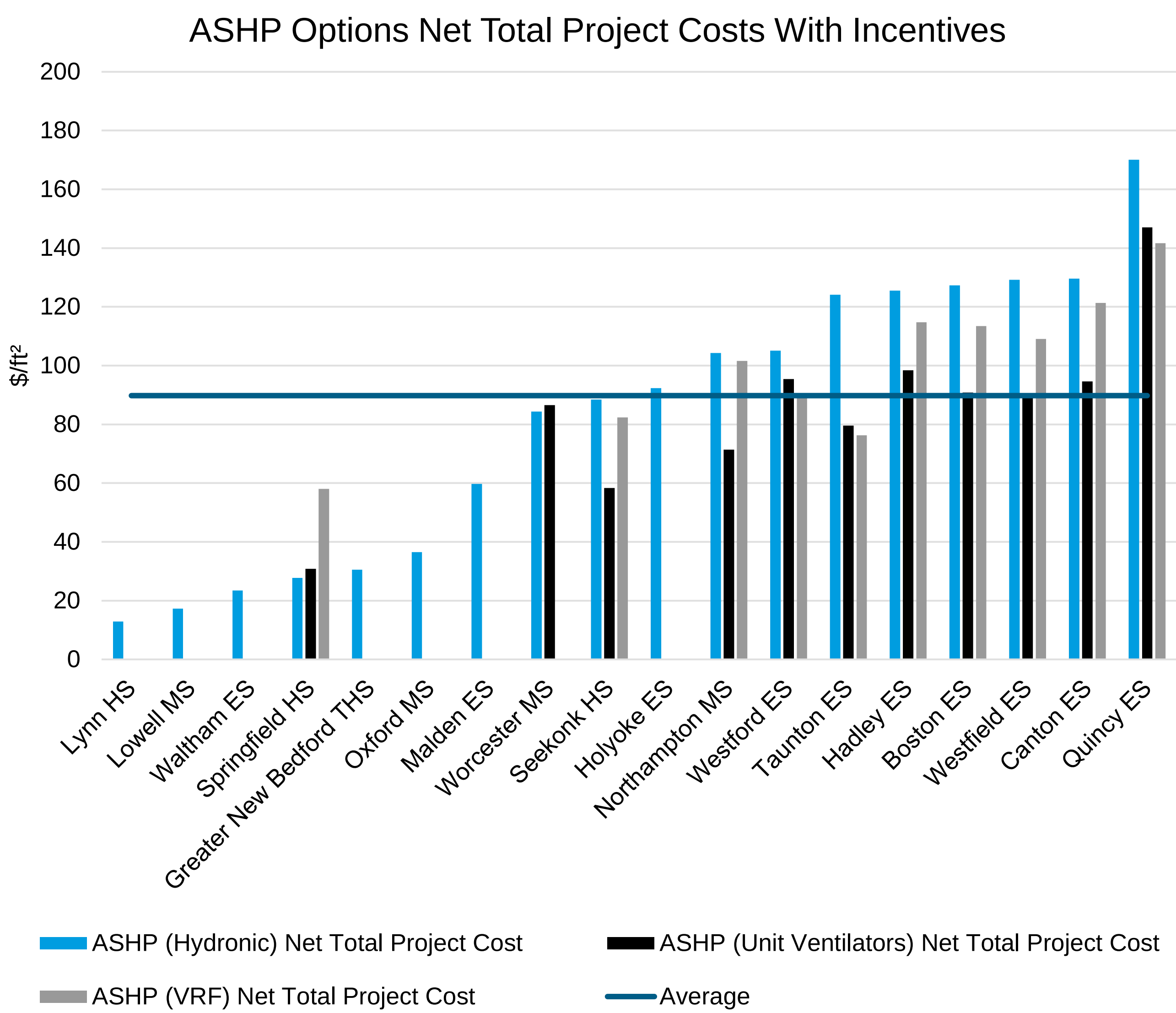


Figure 18

Summary of Project Costs

The total project costs of the proposed options for all 18 schools are shown below. The cost estimates provided as part of this study indicate that there is anticipated to be a wide range of total project costs associated with heat pump conversions across Massachusetts. The largest cost drivers were related to the existing systems within the schools. Where schools already had a significant hydronic distribution designed for both heating and cooling through hot water and chilled water, there was a significantly lower cost of conversion. This is largely due to the assumption of using the existing infrastructure and terminal equipment and limiting the scope of work to the main mechanical rooms and the heat pump system itself. In facilities that currently only have heating, it can be expected that a larger investment may be required due to the necessity to add cooling infrastructure to the building.

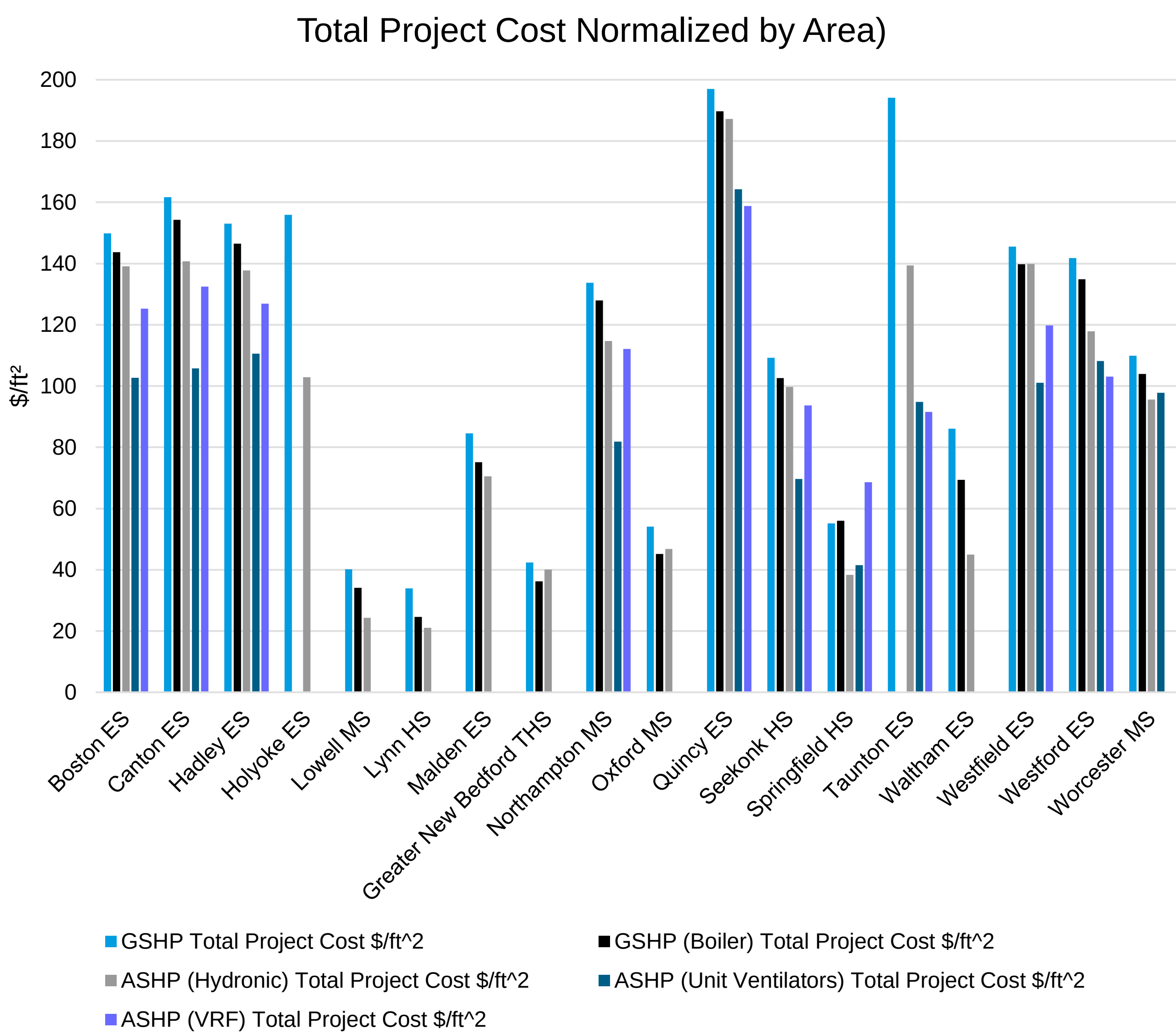


Figure 19

The total project costs with potential rebates and incentives applied is represented in the below figure.

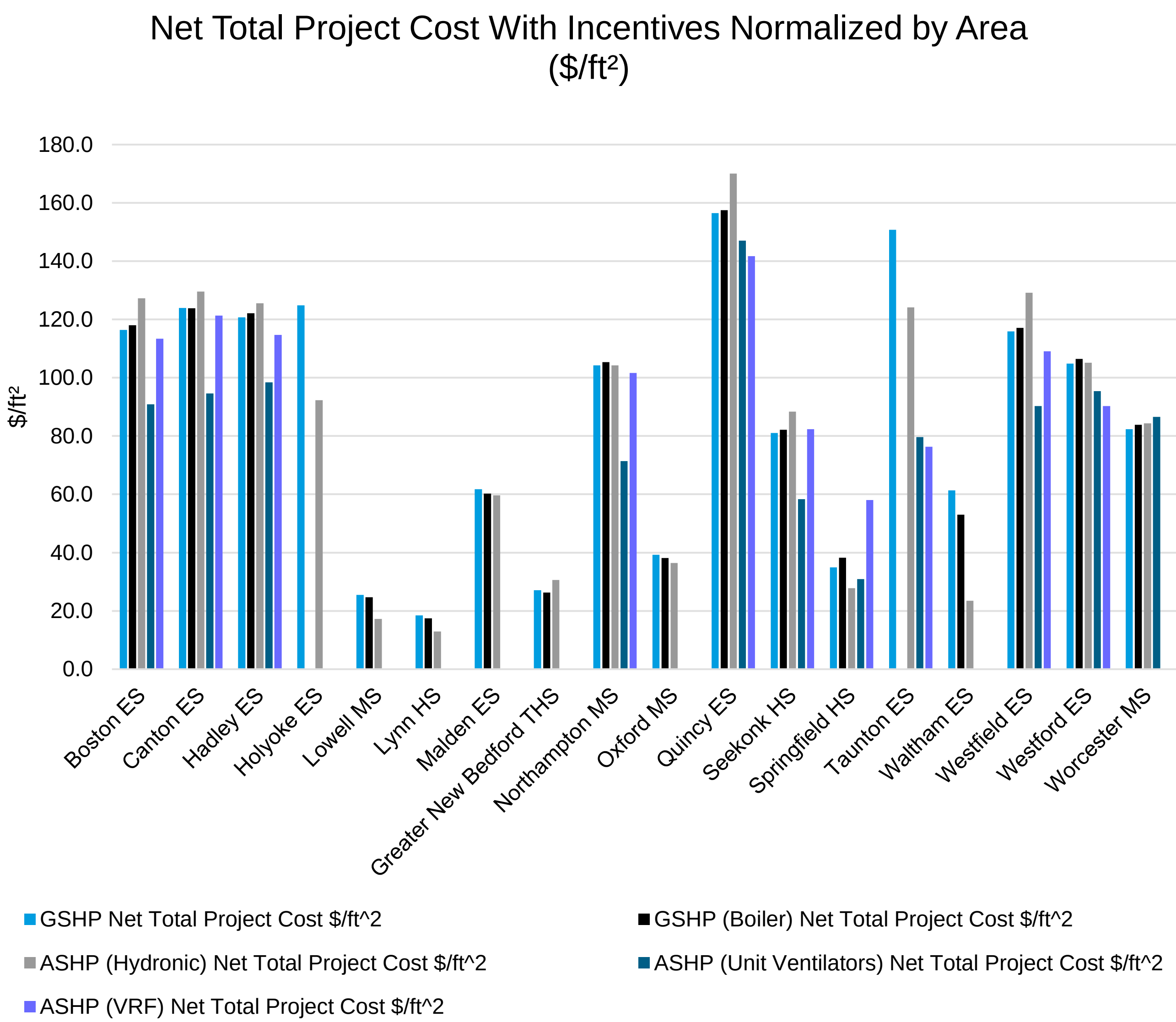


Figure 20

Annual Energy Costs

Annual energy costs analysis is based on estimated annual energy consumption of the proposed solutions and the projected average annual cost of energy.

Estimated Annual Energy Consumptions

- As detailed in the thermal profile and energy analyses section, the proposed heat pump conversion solutions were modeled using historical energy purchases to arrive at the monthly and annual fuel and electricity consumptions of the schools.

Projected Average Annual Cost of Energy

- We have utilized building specific utility cost data provided by the districts.
- This cost has been escalated for the next 30 years using the following rates:
    - Escalation rate for natural gas: 5.24%
    - Escalation rate for oil: 2.52%
    - Escalation rate for electricity: 3.13%

These escalation rates have been sourced from U.S. Department of Commerce's National Institute of Standards and Technology (NIST) Energy Escalation Rate Calculator (EERC). The EERC was used to obtain energy specific escalation rates for 30 years of contract in Massachusetts.

Refer to the individual district sections for more information on the projected annual operating costs.

Life Cycle Cost Analysis

Assumptions

Life Cycle Cost Analysis (LCCA) is a financial assessment method used to evaluate the total cost of ownership of a system or facility over its entire lifespan. It considers initial costs, operating costs, and replacement costs rather than just upfront expenses. The MSBA heat pump study is focused on the cost and impact of converting facilities to heat pump based heating and cooling systems. Although the cost of constructing the recommended systems is high, the other component not addressed in this study is that maintaining a status quo option is not without its costs as well. In order to maintain the current equipment, significant repairs and upgrades may need to be made in the facilities. Those costs are not included in this analysis and shall be evaluated by individual districts.

The LCCA analysis was performed over a 30-year period and shows the buildup of capital costs (CAPEX), purchased fuels and electricity (Commodities), and incentives. All analyses show the solutions for conversions for an assumed 2026 implementation. Some larger facilities that may require a larger scope of work to complete a conversion have been split into two (2) years of construction spanning 2026 and 2027.

The following table represents the assumptions that have been carried throughout the life cycle cost analysis:

Description	Assumption
Inflation Rate:	2.70%
Real Discount Rate:	3.10%
Nat. Gas Escalation Rate:	5.24%
Electric Escalation Rate:	3.13%
Oil Escalation Rate	2.52%
Nominal Discount Rate:	5.88%
Capital Cost Escalation Rate:	4.00%

Summary

The individual life cycle cost analysis for the schools can be found in the sections specific to the district. However, to summarize the general findings for the 18 schools, the data was standardized to a common level by dividing the costs by the school square footage. In schools where certain proposed options were not applicable, they were not included in the life cycle cost exercise. Refer to the specific district section for more information.

The following chart shows the approximate total life cycle costs for the ground source heat pump solution with and without potential incentives.

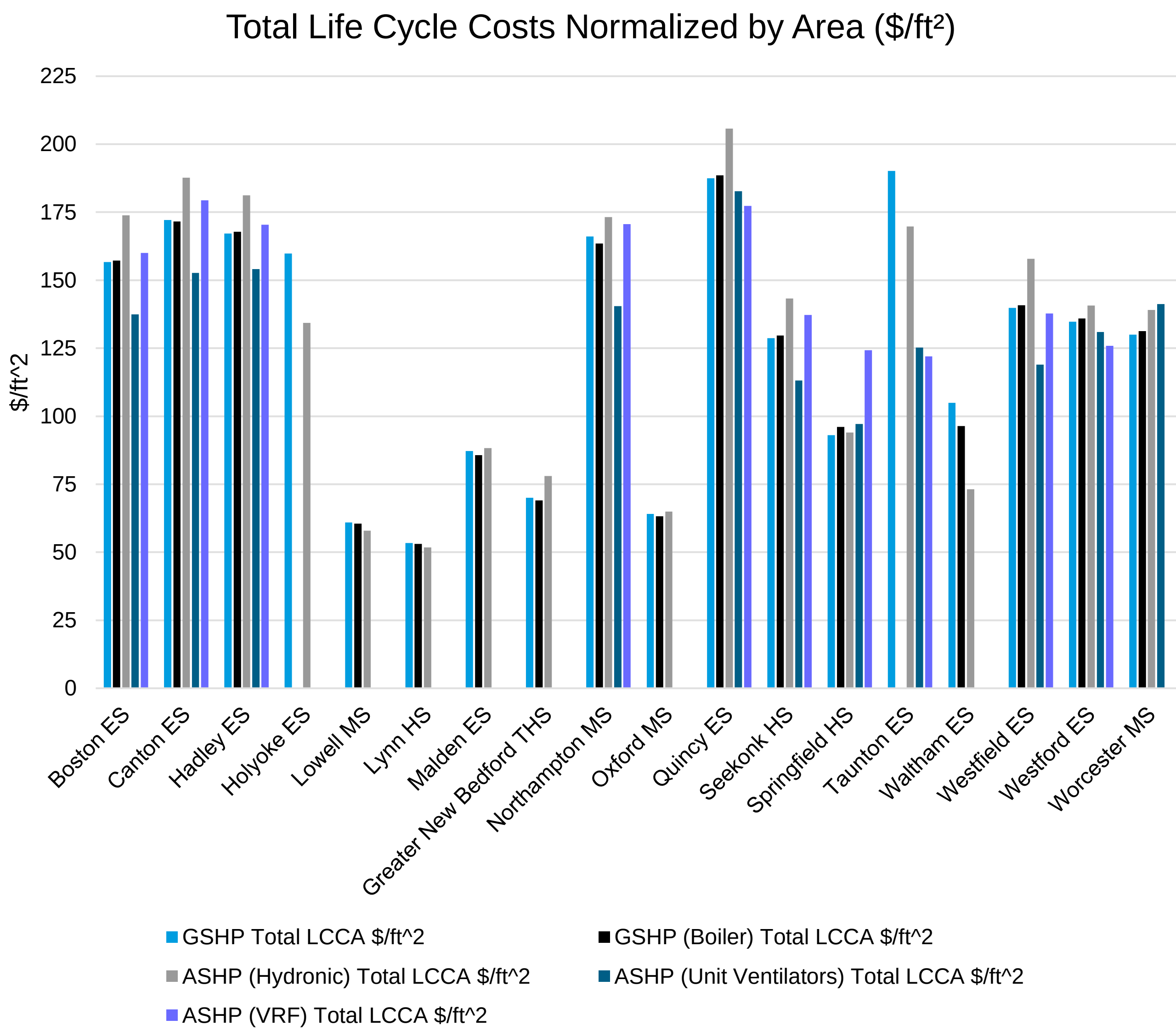


Figure 21

Carbon Emissions Assumptions & Summary

The carbon emission factors utilized for this analysis are 5.3 kg/therm for natural gas and 10.16 kg/therm for #2 Oil. In case of electricity purchased from the grid, a more nuanced approach has been considered. The current grid factor for the Massachusetts region is 245.45 kg/MWh; however, for the purpose of forecasting and analysis, the electricity grid factor has been reduced overtime as more renewable energy assets are anticipated to be brought online. The Commonwealth of Massachusetts has committed to 100 percent of electricity consumed in Massachusetts to be generated by clean and renewable sources by 2050. For our analysis, it was assumed that 100 percent of the purchased electricity would have zero carbon emissions by 2050 with a linear decrease starting at the 245.45 kg/MWh for 2024 emissions, as shown in the figure below.

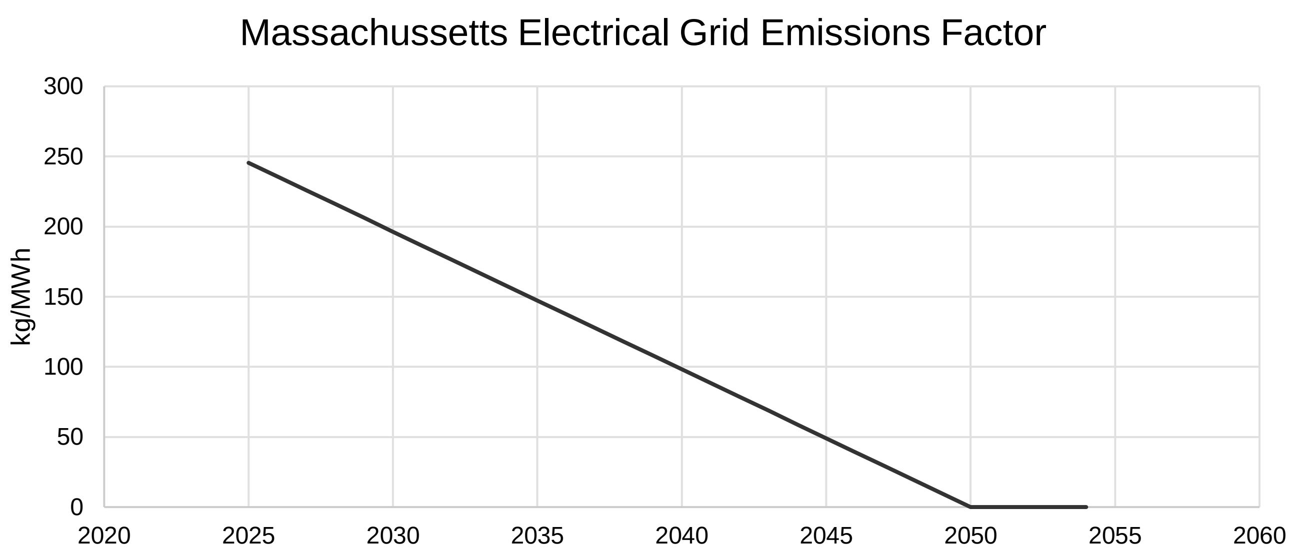


Figure 22 - Assumed emissions from grid electricity

Renewable energy

All greenhouse gas emissions represented in this report are based on the assumption that all electricity is provided by the Massachusetts electrical grid. Any component of renewable energy such as photovoltaic (PV) or purchases of renewable energy credits (RECs) or offsets would further reduce the greenhouse gas emissions below the levels represented in this report.

Life Cycle Greenhouse Gasses

For comparison purposes, a business as usual (BAU) case was developed to simulate if the district was to maintain fossil fuel use the same as it is today. This shows the impact that the heat pump conversion makes over the 30-year life cycle.

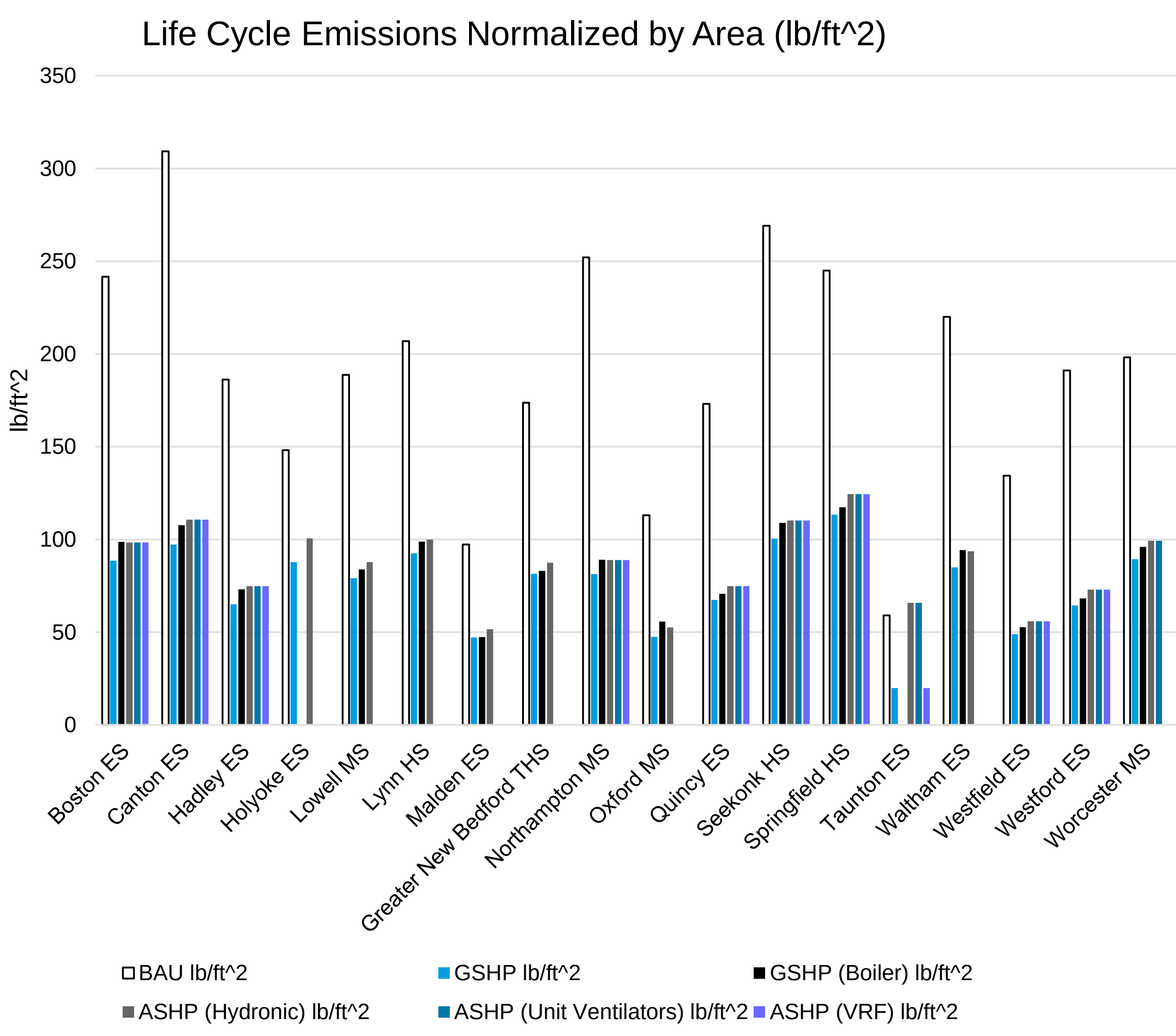


Figure 23

The life cycle emissions clearly shows the significant impact that heat pump conversions would have on the greenhouse gas emissions from the schools. All of the potential solutions provide meaningful progress to reducing the emissions of schools across Massachussets. There is projected to be a small difference in overal emissions over a 30-year period between the different proposed solutions, with the fully electric ground source heat pump option providing the least amount of emissions over the time period.

Project Implementation

As demonstrated herein, there are multiple available options for heat pump conversions with several site-specific factors that go into selecting the proper system for each building. Hence, compared to the traditional ARP program, a more involved and in-depth feasibility/schematic design phase of the heat pump projects is needed to determine the desired heat pump conversion approach and to develop more accurate cost projections for grant approval. From there, an extended construction documents phase encompassing scope beyond the mechanical rooms would be produced to be used for contractor bidding and construction that will ultimately lead to an overall schedule that should be expected to be longer than the past MSBA ARP program cycle.

It is anticipated that the ARP Heat Pump Program will include the following phases:

1. Initial Program Documentation: 3-4 Months
2. Consultant Assignments and Contract Execution: 1-2 Months
3. Feasibility/Schematic Design: 4-8 Months
    a) It is anticipated that this phase length will vary based on proposed scope of work and complexity of conversion
    b) It is recommended that ground source, air source and hybrid heat pump solutions be evaluated at each site
    c) If ground source is chosen as preferred solution, it is recommended to install a test bore to better understand subsurface conditions and more accurately forecast cost and complexity of installation of a geo-exchange bore field
4. Grant approval: 2 Months
5. Construction Documents (CDs): 4-8 Months
    a) It is anticipated that this phase length will vary based on proposed scope of work and complexity of conversion
6. Bidding: 2 Months
7. Construction
    a) One summer (4-6 Months)
    b) Two Summers (4-6 Months per year)
8. Contractor closeout

It is assumed that the approach of the heat pump conversion projects will limit the bulk of the construction to the summer season where the schools are less occupied. It is anticipated that many conversions, especially in the smaller schools, may be able to be completed within one (1) summer period. However, for many of the larger schools and more invasive type of conversions, it is anticipated that the project may need to be split between multiple summers.

For conversions that do not require any work within occupied spaces, such that the only work required is on the heat pump source equipment and connecting into existing systems, it may be feasible to complete that type of work over one (1) summer period.

For schools that may require terminal unit (unit ventilators, fan coil units, radiators, etc.) replacements in all classrooms and occupied spaces in addition to providing a new ventilation system and heat pump source equipment, it may be necessary to extend the construction duration. There are many different ways to approach the phasing; however, one way would be to focus on replacing the terminal equipment and ventilation system over the first summer and supplying it with the existing source equipment. Then the following year replacing the source equipment with the heat pump equipment.

Another approach to phasing could be for schools with different wings or sections with varying systems to do one portion of the building each year until the entire system can be completed. This may require maintaining both the existing system and the new system in the interim or may require additional interior or exterior MEP space for new equipment to be installed while existing equipment remains functional.

Conclusions

The Massachusetts School Building Authority (MSBA) Heat Pump Study has provided valuable insights into the feasibility and benefits of converting existing public K-12 schools to heat pump systems for heating and cooling. The study evaluated 18 representative schools across Massachusetts, analyzing their existing conditions, thermal profiles, energy consumption, and potential heat pump solutions. This study presented several options for the individual districts to consider when evaluating their school for application into the MSBA heat pump program.

As discussed within this report, the schools evaluated were selected based upon the eight (8) priority typology categories with an approximate distribution to represent all schools within the Commonwealth of Massachusetts. The following charts for the typology categories represent the average approximate total project costs, without incentives, of all options evaluated for each school. The estimated cost for any future project would require a complete study of existing conditions and design options.

School Type

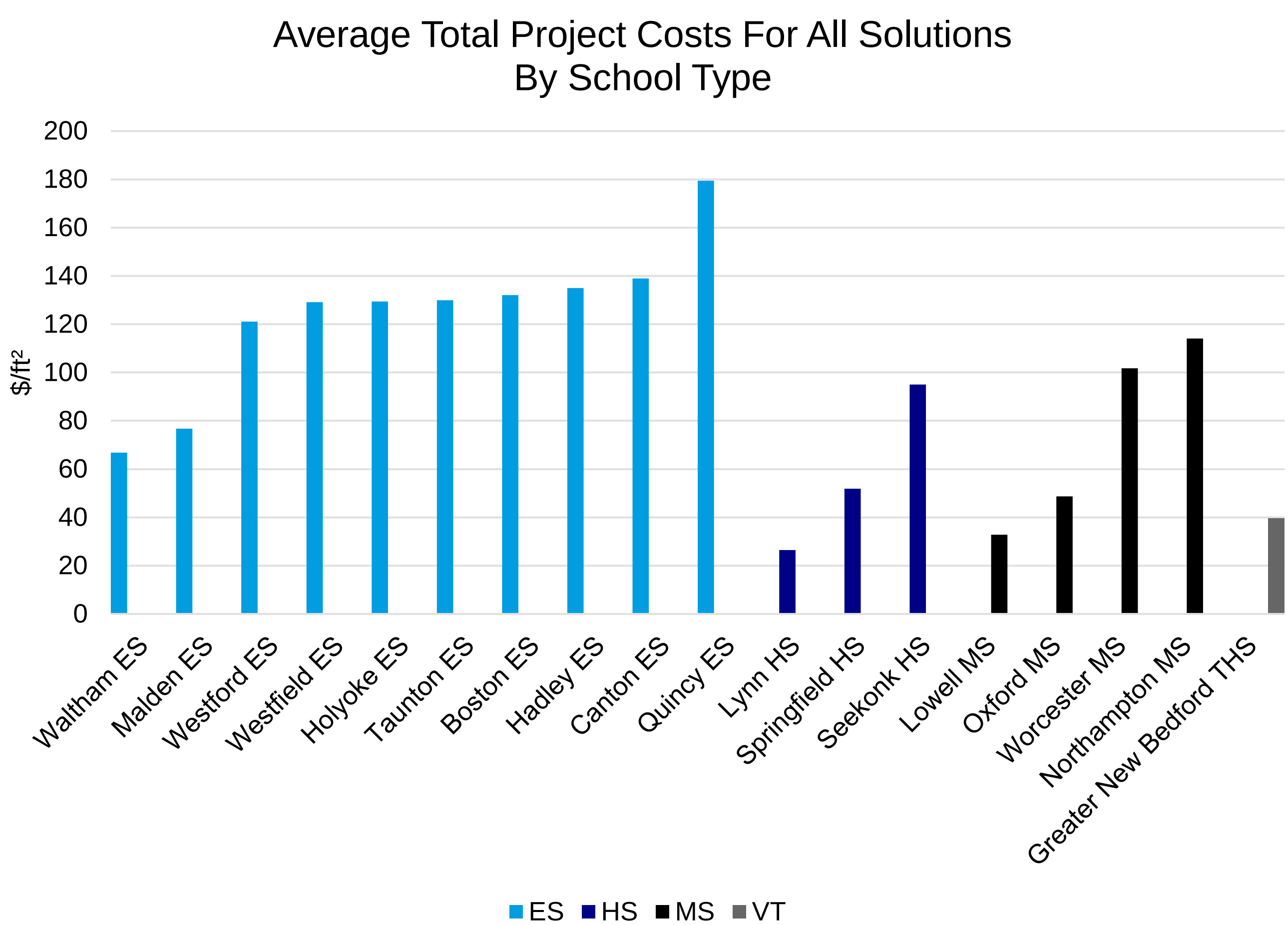


Figure 24

The highest costs appear to occur in elementary schools; however, this may not be directly correlated to the type of school, rather the other typologies such as building size and heating and cooling systems more commonly found in elementary schools.

Age Of Building (Opening Year)

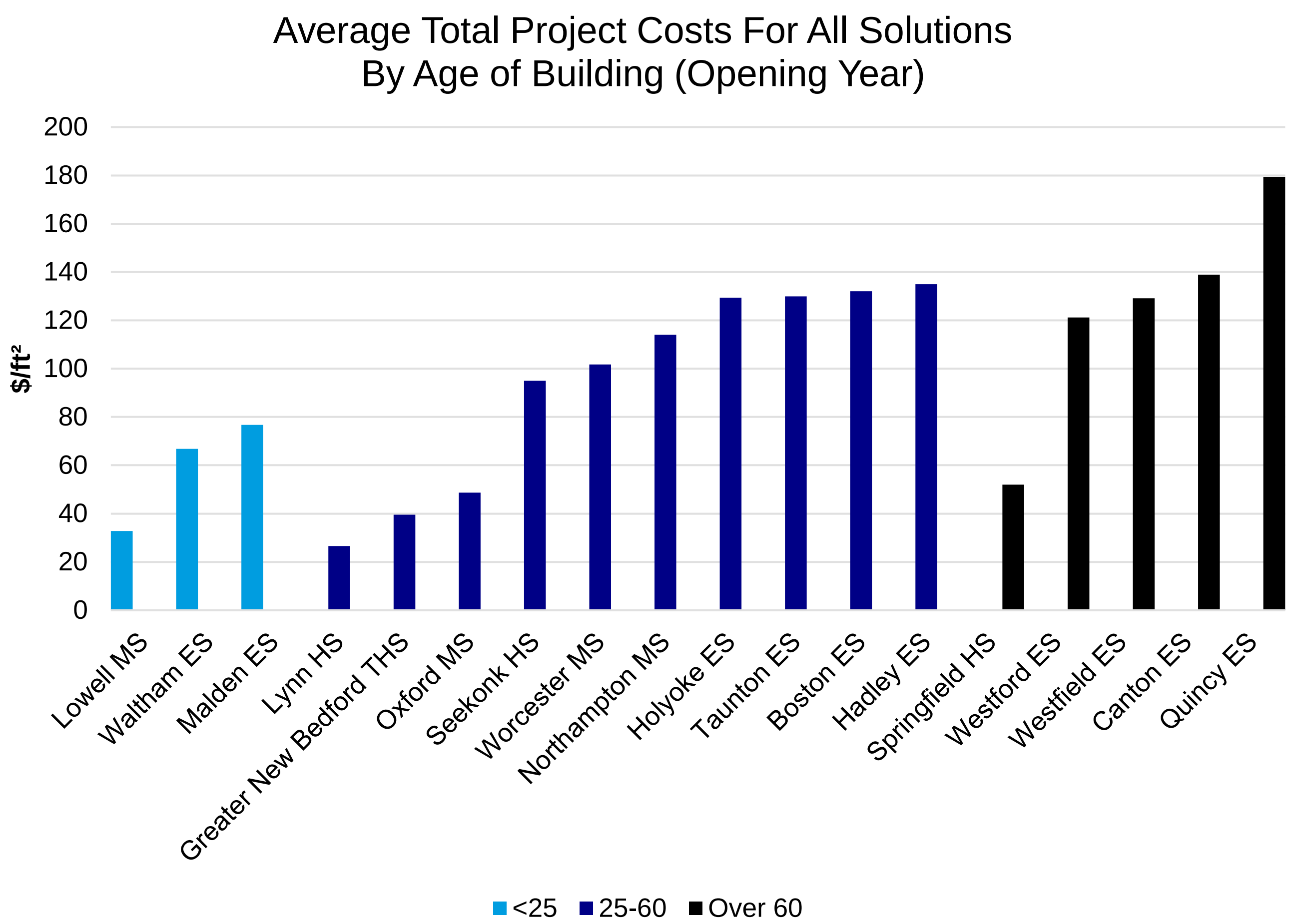


Figure 25

It can be seen that some of the newer facilities may have a slightly lower total project cost per square foot; however, this may also be due to the newer facilities tending to have existing cooling systems. This typology may also provide some insight into the existing conditions of the facilities and whether or not the assumption of reusing existing equipment and infrastructure is feasible. It also provides an insight into the type of system expected in that school, provided it is still the original system. Another component of this typology is that this data is based on the year the school was first constructed and does not represent any major renovations or additions to the school which could skew this data.

Building Size

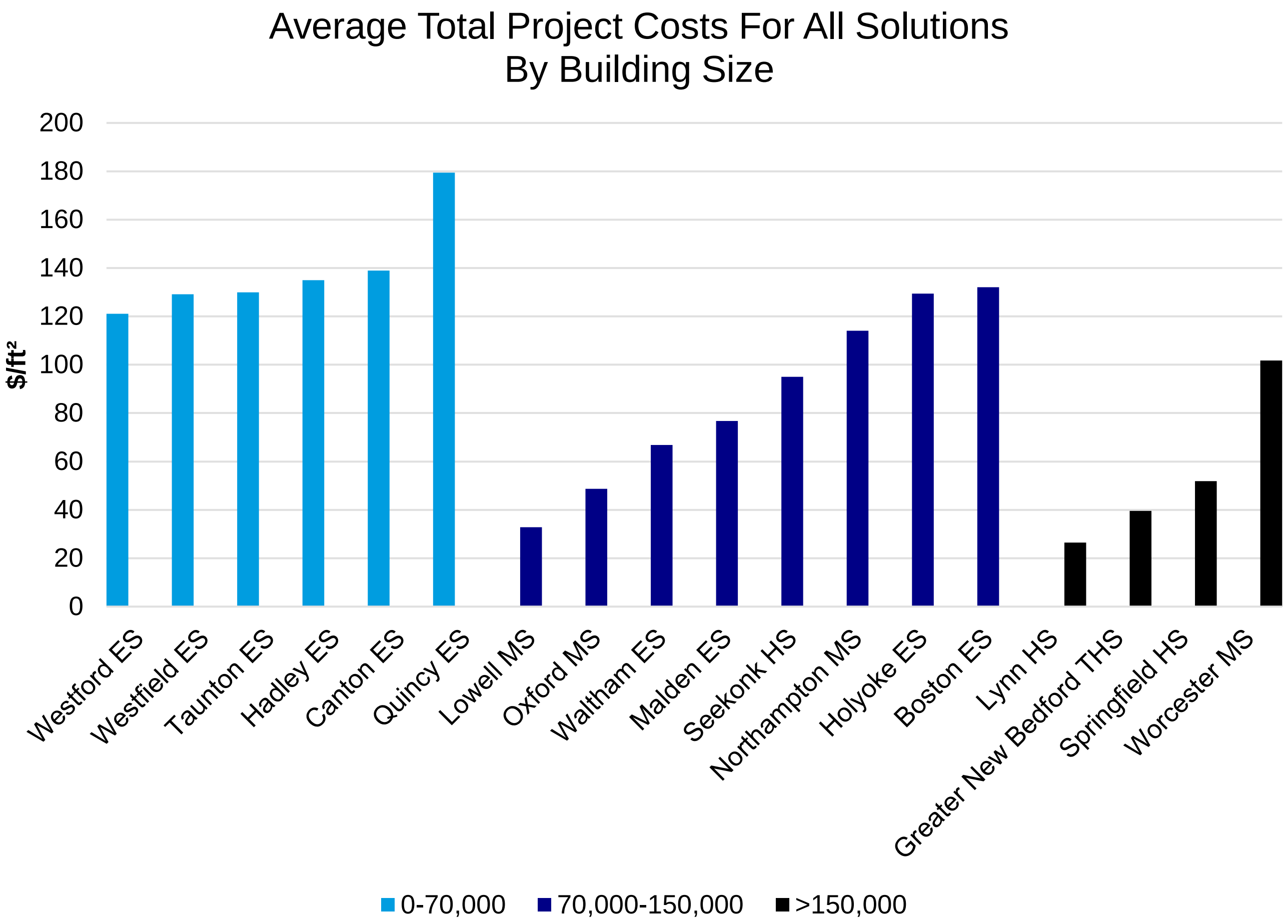


Figure 26

There are some trends seen based on the size of the schools; however, there may be a slight decrease in cost per square foot for the larger schools. This is expected largely due to some economies of scale.

Fuel Source

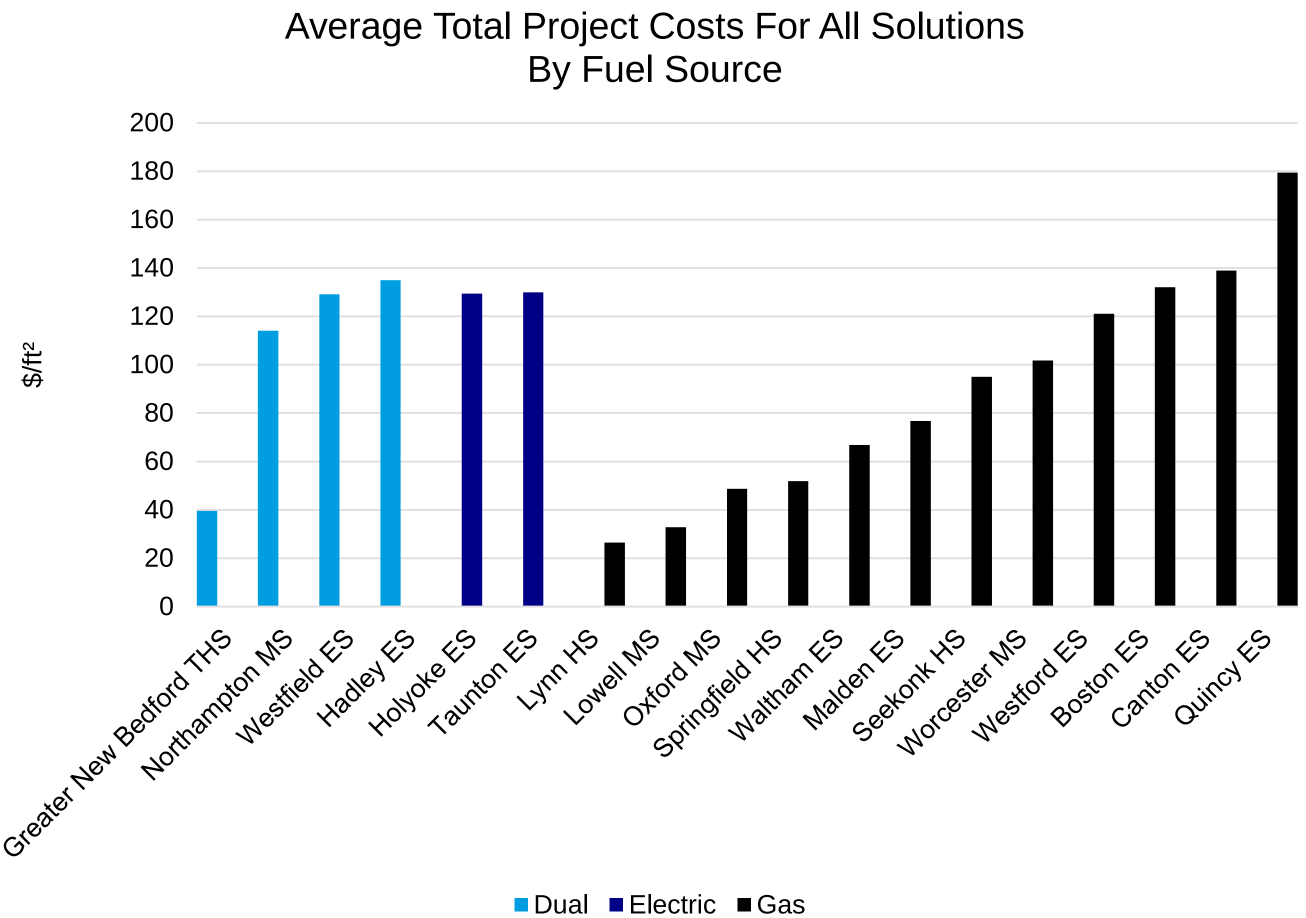


Figure 27

There are no major trends seen related to the fuel source of the existing boiler. This is largely attributed to most facilities utilizing hydronic heating systems fed by a boiler where the fuel source does not impact the work within the buildings. The two caveats are the buildings that are fully electric already. These have a higher total project cost due to the use of electric resistance heating directly within the equipment. Therefore, there is no existing hydronic distribution and therefore all solutions would require full replacement of the existing equipment.

HVAC Distribution Type

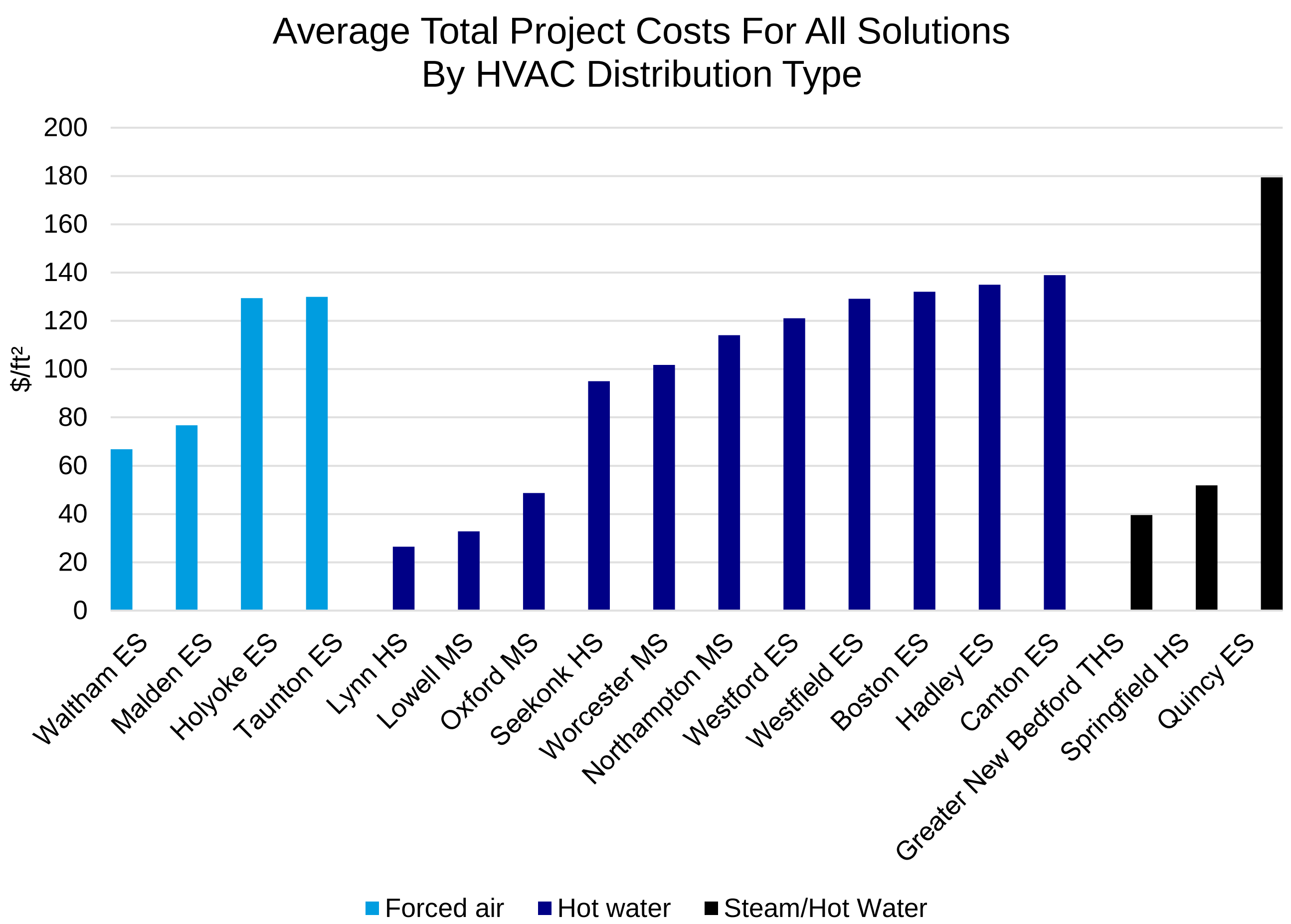


Figure 28

While the heating distribution type provides some insight into the potential scope of work required for a heat pump conversion, there is still a broad spectrum of work required for the facilities. There is some benefit from having a hot water system within the facilities, as it was assumed that the hot water system could be reused; however, it does not directly corelate to the overall expected cost as it is only half of the overall system. Regarding the schools that have steam, Greater New Bedford and Springfield are substantially hot water-based distribution systems with some steam left in place mainly serving the hot water systems through heat exchangers. Greater New Bedford also utilizes the steam infrastructure for teaching purposes. It should be assumed that schools with significant steam infrastructure and terminal equipment would require significant investment on the higher end of the spectrum of costs.

Cooling Distribution

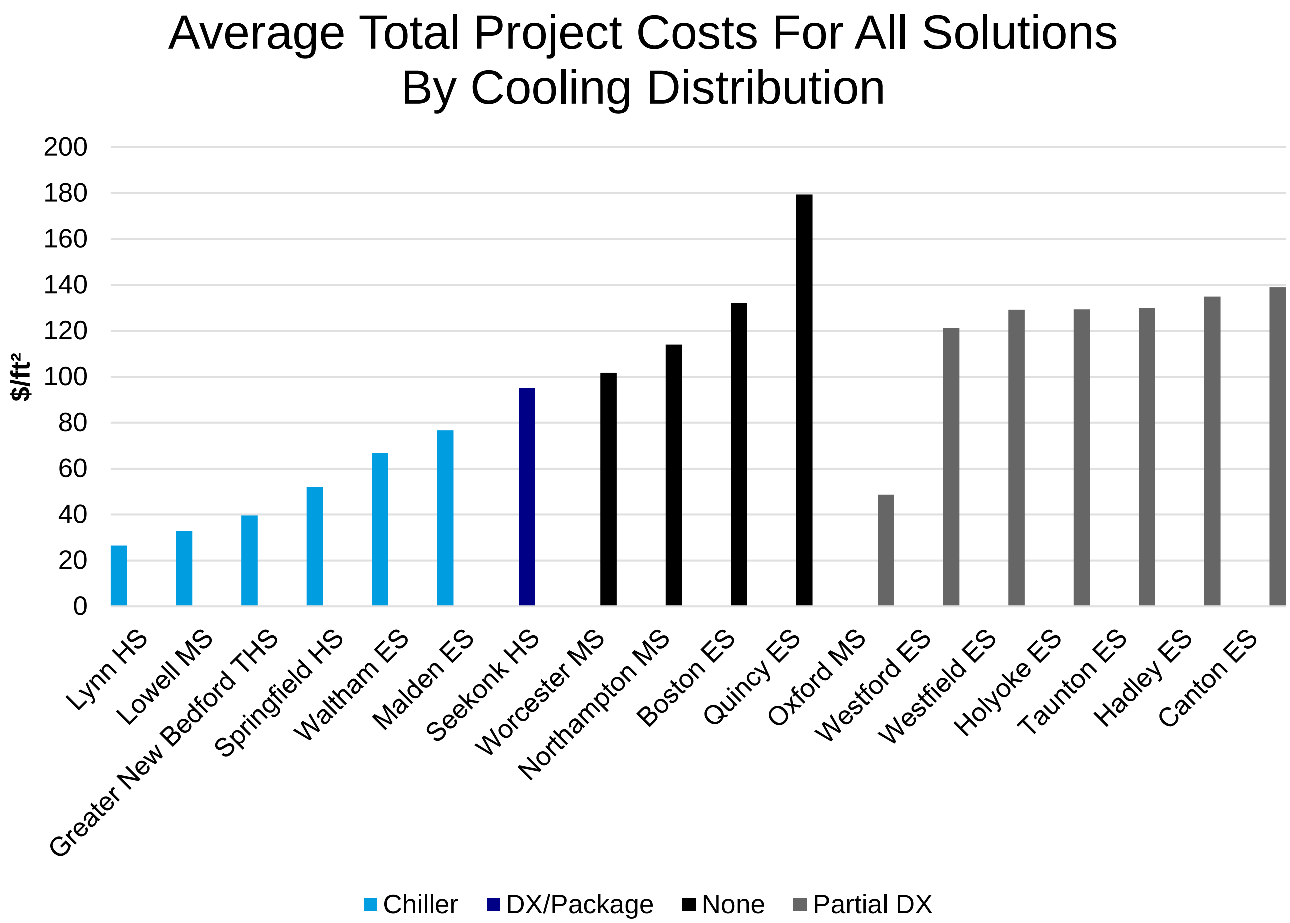


Figure 29

There is a reasonable correlation between the schools that have current chiller systems and the overall cost to convert. This is largely due to the fact that schools with chillers have chilled water infrastructure and cooling in the majority of the buildings. This leads to being able to reuse the existing terminal equipment and air handling equipment and limiting the scope of work to the mechanical rooms and heating and cooling generation equipment. The one (1) outlier is Oxford MS, which is due to the school having a recent HVAC replacement where the facility was planned for cooling through the use of dual temperature piping. However, the chiller was not installed as part of the renovation. Therefore, this makes this facility similar to those that do have a chiller in the sense that no building side work with new piping or equipment within classrooms is required.

Roof Area to Site Acreage Ratio

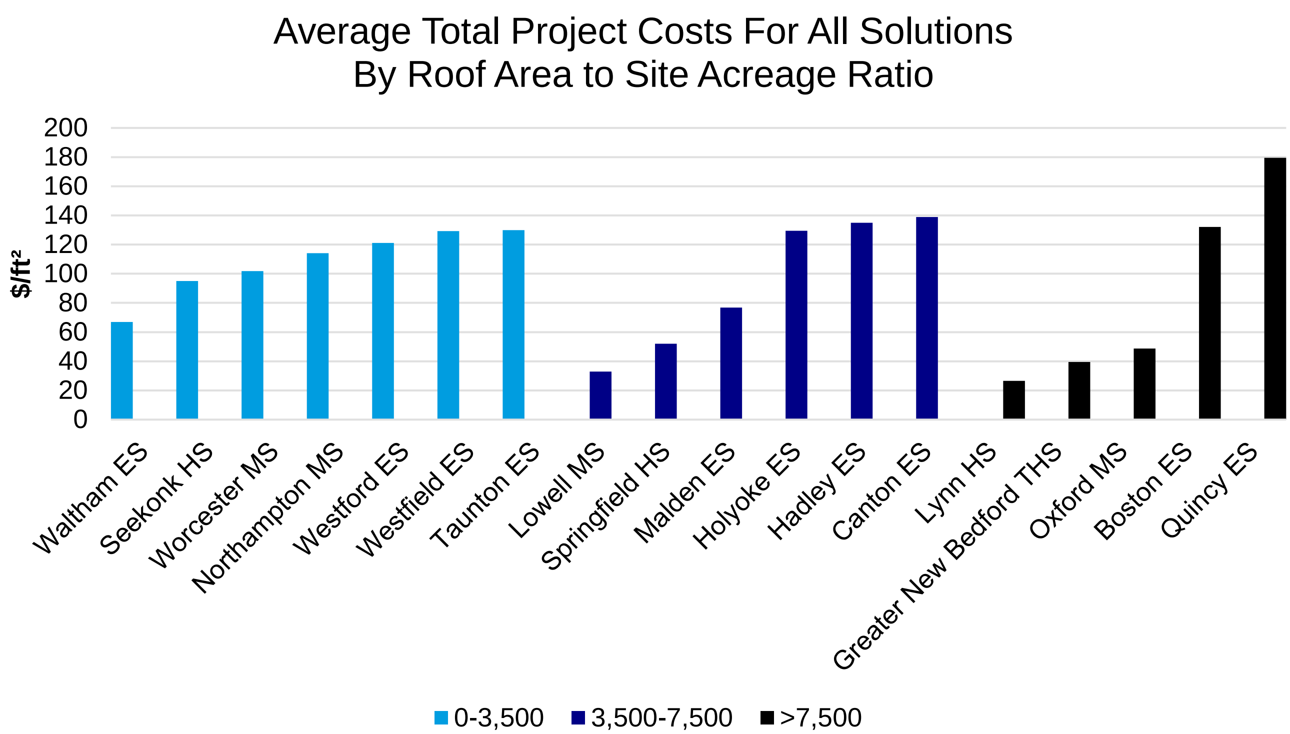


Figure 30

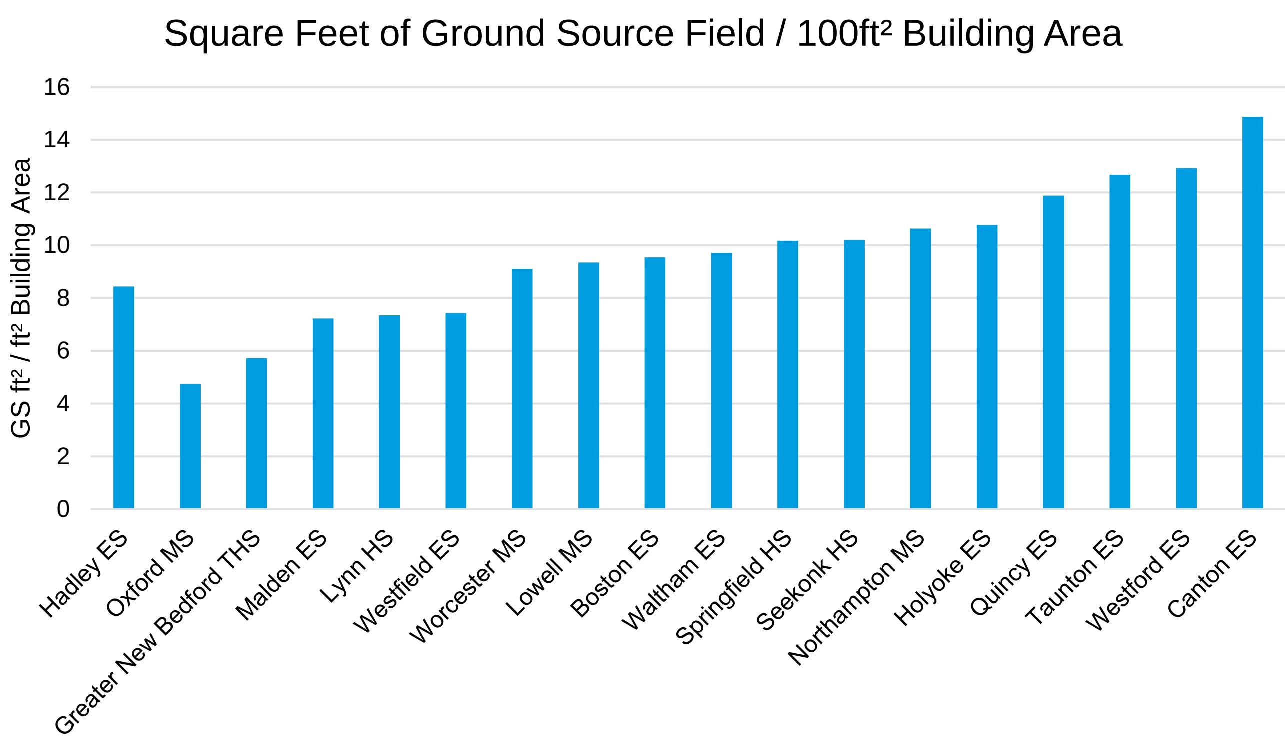


Figure 31

There are not significant trends within the cost of the ground source option. This is largely due to the optimization exercise that was completed and the hybrid approach that has been presented in this study. Utilizing a hybrid approach allows the costs to be better focused on utilizing equipment where it is the most efficient, therefore minimizing the ground source cost. Additionally, the hybrid approach reduced the required land area for the ground source system, and therefore all evaluated facilities appeared to have sufficient space to install a ground source system based on the limited review. In some cases, this would require drilling within a parking lot, playground, or sports field. It is expected that any districts interested in pursuing a ground source solution will evaluate its specific land area further.

Probability of Electrical Capacity for Heat Pump Conversion

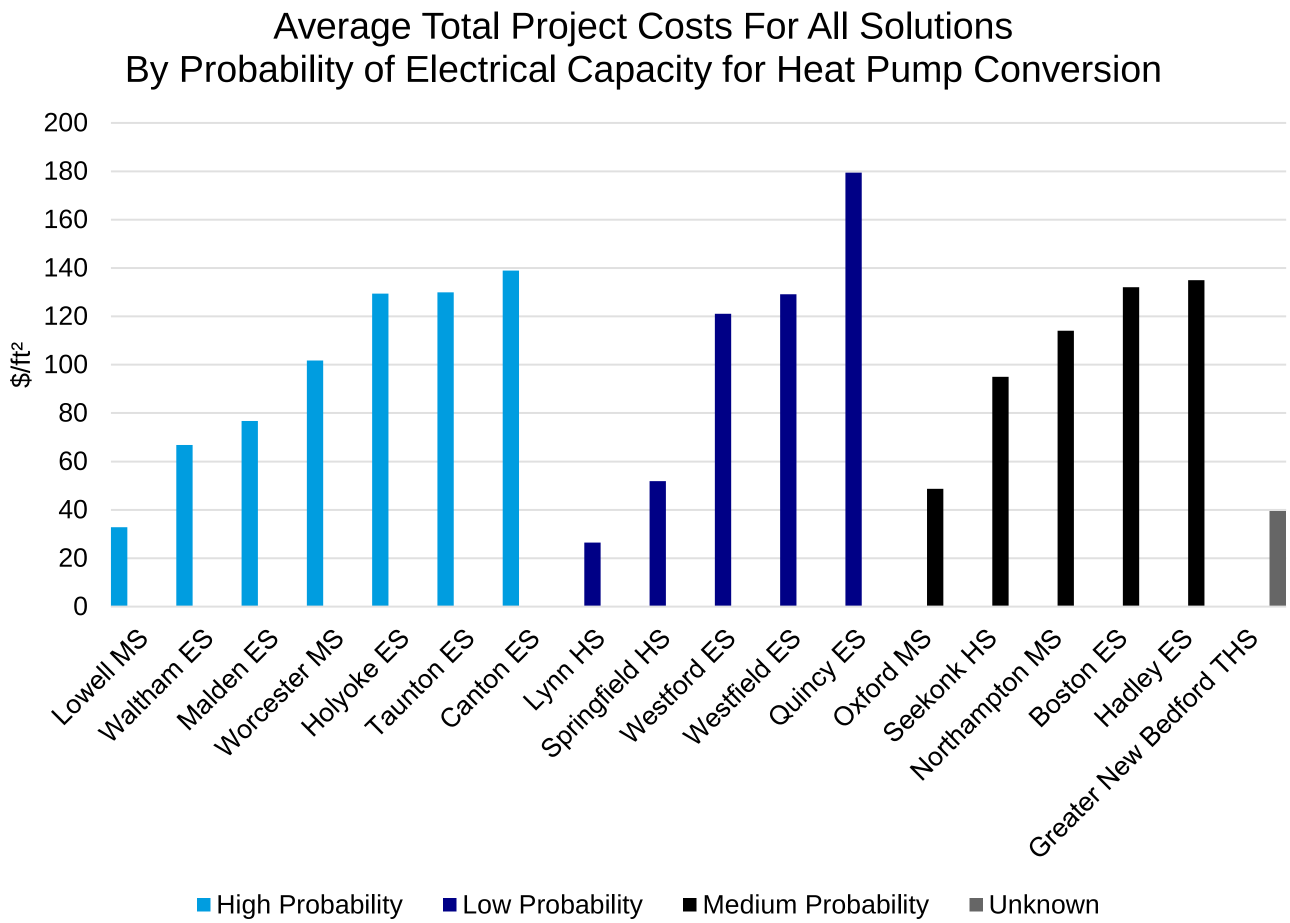


Figure 32

While the probability of electrical capacity did not directly correlate to the overall cost to convert, it was found that it was a reasonable approximation to what facilities might need to be upgraded. Based on the limited review, it is anticipated that approximately half of the facilities may require a significant electrical upgrade to complete a heat pump conversion. In facilities with current cooling, this can largely be mitigated through the use of a fossil fuel boiler for the peak heating as discussed within this report.

Scope of Work Summary

While there are many components that contribute to a heat pump conversion of a school, a few major items are considered for determination of an approximate scope of work of a conversion. Through the course of this study, it has been determined that the largest contributing factor to the cost of a heat pump conversion will be related to the existing HVAC systems within the facilities. The following represent some of the major guiding questions and information that would provide a beneficial insight into the type of heat pump conversion the school may require.

Existing Equipment Categorization

- Does the School have an existing high efficiency boiler in good working condition?
- What existing piping does the school have?
    - Hot Water
    - Chilled Water
    - Dual Temperature water
- What is the Main HVAC System?
    - Centralized Air handling units with or without VAV reheat
        - Heating Only
        - Heating and cooling
        - Chilled water or DX
    - Terminal Units
        - Heating Only
        - Heating and cooling
    - Ventilation
        - Centralized system (AHU or DOAS)
        - Point of use (unit ventilators)
            - Ventilation
                - Centralized system (AHU or DOAS)
                - Point of use (unit ventilators)

Heat Pump Conversion Considerations:

- Is new terminal equipment required to facilitate both heating and cooling?
- Are new air handling units required to facilitate both heating and cooling?
- Is new piping required to facilitate both heating and cooling?
    - Are both hot water and chilled water piping required?
    - Is only chilled water piping required?

- Is a new Ventilation system requested or required?
    - Is the desire to provide a new modern ventilation system (DOAS)?
    - Is there available roof or site area to install new DOAS?
    - Is there ceiling cavity space for ductwork? Is rooftop ductwork acceptable?
    - Are replace in kind unit ventilators acceptable?
- Is there available site/land area to allow construction of a ground source field?
- Is there available roof or site area to install air source heat pumps?
- Is the building currently sprinklered?
- Does the building meet current accessibility requirements?

These major levers relating to the current HVAC systems provide insight into the level of investment and disruption that may be required for a heat pump conversion of a specific school. It is acknowledged that every school may not fall into one of these representative categories and that many schools will associate with a combination of the categories, but the following represent some broad categorization of potential type of work required for a heat pump conversion, ordered from least amount of work to largest amount of work.

Distributed terminal equipment/ventilation:

1. Install Heat pump source equipment and connect into existing to remain HW and CHW systems.
2. Install heat pump source equipment, replace terminal equipment, and install new ventilation system.
3. Install heat pump source equipment, install new piping, and replace unit ventilators in kind.
4. Install heat pump source equipment, install new piping, replace terminal equipment, and install new ventilation system.

Centralized Air handling equipment and duct distribution:

1. Install Heat pump source equipment and connect into existing to remain HW and CHW systems.
2. Replace select coils within existing to remain central air handling equipment with hot water and chilled water coils, or dual temperature coils.
3. Replace existing central air handling equipment with heating and cooling capable air handling equipment.
4. Replace existing central air handling equipment with heat pump-based equipment.

Accelerated Repair Program Considerations

The other components of the MSBA program include window replacements and roof replacements. Both of these programs would provide an added benefit to the heat pump conversion program. It is recommended that if the district is considering a heat pump conversion that incorporates installing equipment on the roof, that a roof replacement is considered at the same time. The window replacement would provide an additional energy conservation measure that would reduce the overall load of the school and could impact the heat pump sizing. While it is not necessary to complete a window and/or roof replacement prior to a heat pump conversion, there may be significant energy and equipment benefits.

Summary

Each of the solutions presented within this report provide a feasible opportunity for a school to participate in a heat pump conversion. It has become clear through this study that there is a broad range of scope of work that would be required for a heat pump conversion based on the individual school. It appears from this study that many schools that currently have a hydronic heating and cooling system may be well suited for a smaller scope of work whereas schools that do not currently have cooling may require a larger project to accomplish a heat pump conversion.

The results of this study indicate the average projected total project cost for a heat pump conversion as presented in this report is between $25/SF and $180/SF. While this is a significant range of costs, there are some trends that can be seen from the building typologies selected.

The highest costs appear to occur in elementary schools and schools that are older than 60 years since the original opening date. However, this may not indicate a correlation to these typologies, but rather to the building size and heating and cooling systems that typically appear in these types of schools. The elementary schools that were over 60 years old had a high probability of utilizing heating only unit ventilators as the primary heating and ventilation system. This type of school would require a larger scope of work to complete a heat pump conversion, especially with a new dedicated outdoor air system for ventilation.

Additionally, the costs for the smaller schools tended to be slightly higher, and while this may be partially related to economies of scale, it also may be related to all of the smaller schools being elementary schools, which leads to the same potential correlation associated with existing heating and ventilation systems referenced above. This provides some insight that elementary schools that are older than 60 years old and are less than 70,000 GSF may not directly indicate that a school would require a larger project cost per square foot to convert. However, it does suggest a higher probability of having heating only unit ventilator systems that would indicate a higher project cost per square foot.

Another interesting insight observed is that high schools tended to be larger facilities which also tended to have a chiller-based cooling system. This is typical in the industry where larger facilities will tend to have chiller systems with a chilled water distribution. This indicates that larger high schools that currently have cooling may require a lower cost to convert as they have a higher probability of having a hydronic heating and a cooling system.

It is recommended that districts evaluate the project first costs alongside the life cycle costs, the advantages and disadvantages of the individual systems, and the overall condition of the existing equipment within the school. All three factors should be considered within a comprehensive evaluation of the right pathway to pursue for the individual school. Through a more detailed feasibility and schematic design phase, the districts can further evaluate and determine which pathway may be the right pathway for them.

As can be seen by the emissions section of this report, any and all heat pump conversions will make a significant difference in the greenhouse gas emissions of that facility over the next 30 years.

Individual School Sections

William Monroe Trotter School, Boston, MA

Dean Luce Elementary School, Canton, MA

Hadley Elementary School, Hadley, MA

Maurice Donahue Elementary School, Holyoke, MA

Stoklosa Middle School, Lowell, MA

Lynn Classical High School, Lynn, MA

Ferryway Elementary School, Malden, MA

Greater New Bedford Regional Technical Vocational High School, New Bedford, MA

JFK Middle School, Northampton, MA

Oxford Middle School, Oxford, MA

Merrymount Elementary School, Quincy, MA

Seekonk High School, Seekonk, MA

Springfield High School of Science and Technology, Springfield, MA

Edmund Hatch Bennett Elementary School, Taunton, MA

Douglass MacArthur Elementary School, Waltham, MA

Southampton Road School, Westfield, MA

Nabnasset Elementary School, Westford, MA