ASSESSMENT OF BUILDING ELECTRIFICATION TECHNOLOGIES FOR NEW YORK STATE

An assessment of the potential role of current and emerging electric technologies in buildings to meet energy needs and resulting impacts on end-use energy efficiency, carbon emissions, economics, and electricity demand through 2050

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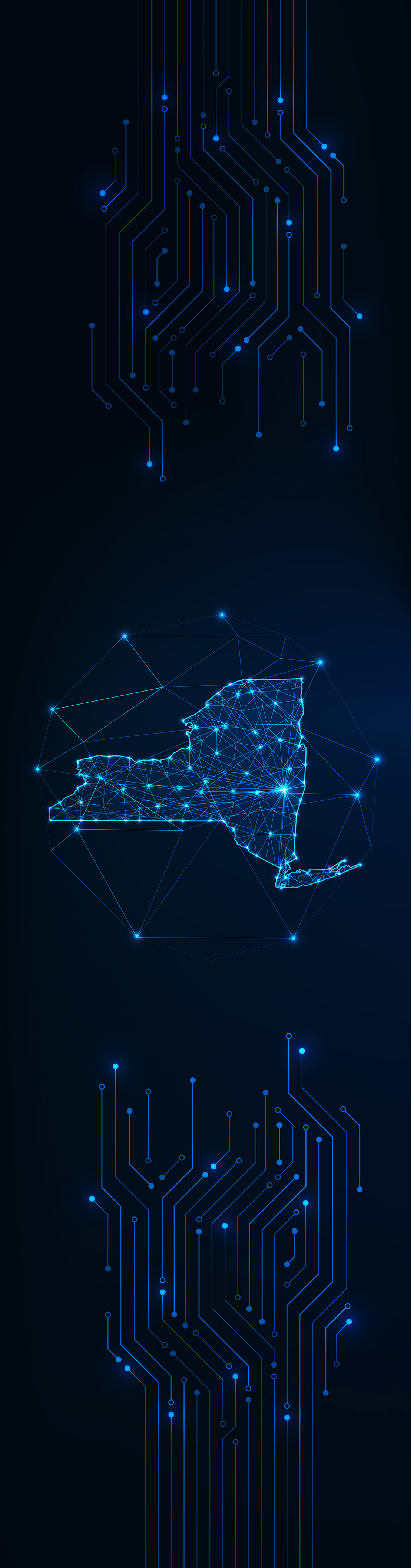

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ACKNOWLEDGMENTS

This report was prepared by EPRI.

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CONVERSION FACTORS

The following table presents conversion factors for the units of measure used in this report.

U.S. STANDARD UNITS	INTERNATIONAL SYSTEM OF UNITS (SI)
1 ft	0.305 m
1 ton (12,000 Btu/h)	3.52 kW
1 Btu	1055.05 J
1 kWh	3.6×10^{6} J
32°F	0°C

ACRONYMS AND ABBREVIATIONS

AC	air conditioning
AEO	Annual Energy Outlook
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BTU	British thermal units
CARD	Conservation Applied Research and Development
CLCPA	Climate Leadership and Community Protection Act
C	Celsius
CEE	Center for Energy and Environment
CO_2	carbon dioxide
Con Edison	Consolidated Edison Company of New York, Inc.
COP	coefficient of performance
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EPRI	Electric Power Research Institute
F	Fahrenheit
ft^2	square feet
GHG	greenhouse gas
GW	gigawatt
GWh	gigawatt hours
HSPF	heating season performance factor
HVAC	heating, ventilation, and air conditioning
IEER	integrated energy efficiency ratio
kcal	kilocalorie
kW	kilowatt
kWh	kilowatt hours
MMBtu	1 million British thermal units
NEC	National Electrical Code
NPV	net present value
NREL	National Renewable Energy Laboratory
NY	New York
NYISO	New York Independent System Operator
NYPA	New York Power Authority
NYSERDA	New York State Energy Research and Development Authority
RTU	rooftop unit
SEER	seasonal energy efficiency ratio
SI	International System of Units
U.S.	United States
VRF	variable refrigerant flow
W	watt

EXECUTIVE SUMMARY

"Assessment of Building Electrification Technologies for New York State" provides detailed electrification outreach implementation strategies and recommendations for EPRI utility members within the state. This research builds on "Electrification Scenarios for New York's Energy Future," a 2019 work undertaken with major New York electric utilities, and examines the electrification impacts such as CO_2 emissions, demand impacts and energy use for building end-uses such as space and water heating and cooking. It comprehensively examines efficient building electrification space heating technologies that could play a significant role in reaching the state's energy and carbon goals, including those outlined by the Climate Leadership and Community Protection Act (CLCPA) which was enacted following the above 2019 study.

For this study, EPRI collaborated with utility stakeholders (Consolidated Edison Company of New York, New York Power Authority, New York Independent System Operator, and Central Hudson), to create awareness about various building space heating electrification solutions available to New York residents and businesses. EPRI also involved the New York State Energy Research and Development Authority (NYSERDA) in a consultation role. The resulting data sharing and discussions between the stakeholders enabled EPRI to highlight the market adoption potential of heat pumps, along with their role in reducing energy consumption, carbon emissions, lifecycle costs, and peak demand.

Key highlights from the study are as follows:

- **A variety of heat pumps are available to meet building space heating needs. These include air-source heat pumps, cold-climate air-source heat pumps, geothermal heat pumps, dual-fuel heat pumps, ductless/variable refrigerant flow heat pumps, and rooftop heat pumps.** Customers select from these options based on factors such as building construction, heat pump performance, resulting customer cost, carbon emission reduction potential, and consumption of electrical energy.

- **Heat pumps reduce carbon dioxide (CO_2) emissions in heating and cooling end-uses by 5–40% compared to gas boilers and gas furnace based heating systems combined with window and central air conditioners.** Among different heat pump types, dual-fuel heat pumps have the lowest emission reduction potential (5–15%), followed by air-source heat pumps with electric resistance backup (10–20%). Higher-efficiency systems such as cold-climate heat pumps and ground-source heat pumps can reduce emissions by more than 30% due to their lower energy consumption.

- **Heat Pump Installations in the field show that various heat pumps meet building heating load at efficiency levels—measured by coefficient of performance (COP)—varying from 1.2–3.6. Ground-source heat pumps are two to three times more efficient than standard efficiency (single-speed) air-source based heat pumps with electric resistance or gas backup.** The difference in energy consumption between heat pump types is greatest during the coldest hours of the year when, for example, air-source based heat pump efficiency decreases significantly while geothermal heat pumps do not experience a noticeable change in efficiency. More-efficient air-source based heat pumps, such as cold-climate ducted heat pumps and cold-climate ductless heat pumps[1] have annual heating efficiencies that fall in between that of ground-source heat pumps and standard efficiency air-source heat pumps. Peak demands modeled based on manufacturer data of specific cold climate heat pump models show a reduction of 8–10% compared to the peak demand consumption of a single-speed air-source heat pump with electric resistance backup.

1 Many of the ductless heat pumps available in the market today are also cold climate models. However, this report specifically refers to ducted systems when any analysis results are presented with respect to "cold climate heat pumps".

- Heat pumps have higher lifecycle costs than fossil-fuel based heating equipment.[2] **Natural gas technologies generally remain the most cost-effective option available today.** Key reasons for heat pumps' higher lifecycle costs include the greater upfront cost premium for various heat pump types (both air-source based and geothermal heat pumps), as well as the added cost of retrofit components, including the customer's potential electrical infrastructure upgrade needs. In particular, heat pump lifecycle costs for large residential and commercial buildings are significantly higher than a gas boiler and electric AC, and retrofits of large buildings are significantly disruptive to tenants who will likely have to relocate. Among the various heat pump technologies, air-source based heat pumps are more cost effective than geothermal heat pumps.

2 Note that cost-effectiveness here has been assessed from a customer point of view, not from a societal lens.

- **Under a reference scenario in which future adoption is driven solely by the economics of heating, ventilation, and air conditioning systems, the market share of natural gas technologies increases through 2050.** Despite propane and fuel oil usage declining during this period, the state's **greenhouse gas (GHG) emission targets specified in the CLCPA are not met.** Energy efficiency measures (including building envelope and end-use energy intensity improvements) are expected to offset increases in electric energy consumption due to electrification.

- New York State has a significant stock of existing housing such as single-family homes and low-rise buildings that was built under older energy codes, and as a result incur increased HVAC energy consumption. **Upgrading the envelope of these existing buildings as per the new energy code specifications will reduce the cost and size of heating equipment, as well as the amount of supplemental heating needed.** On an average, improved building envelopes can reduce space heating energy consumption by 10–18%, which in turn enables a larger reduction in carbon emissions. For new buildings that are constructed with the more recent energy codes, heat pump installations can be sized up to 25% smaller than existing buildings, reducing the overall cost of heat pump installation.

- **Analysis of heat pump installation field studies in colder U.S. climates has helped align modeling results with real-world observed heat pump efficiencies.** Though the sample size used for this exercise was limited, heat pumps' field measured heating efficiencies (COP) exhibit a ~10% reduction relative to efficiencies that are directly modeled using published equipment performance data. This is understandable, given that heat pump efficiencies in the field depend on several factors, such as operation style, occupant behaviors (e.g., temperature setbacks), and age of equipment. On the coldest days, when the outside air temperature ranges between 0°F and 10°F, the field observed heating COPs of air source heat pump cycle falls between 0.95–1.75. Additional field studies can help to quantify these heating efficiency values more accurately.

- **Reviews of field installations provide clearer insights into design considerations for heat pump sizing, installation, operation, and maintenance.** Heat pumps in the field are historically sized for cooling needs and therefore are not designed to meet the full heating needs in heat pump only mode (i.e. without backup). Sizing heat pumps for heating needs (as is encouraged by heat pump installation incentives that are available under the New York State Clean Heat program) can prevent their dependence on backup heat, but this comes at an additional cost.

- Evolution of consumers' heat pump technology adoption in buildings can occur under multiple heating electrification pathways or scenarios. **Shifting to electric heating equipment to meet CLCPA GHG emission targets causes the New York electric system to change from summer to winter peaking in all scenarios.**

- **Aggressive, policy-driven scenarios could initiate significant changes in buildings' overall energy-use mix** (increases in electric and decreases in fossil fuel consumption), **enabling New York to meet its 2050 carbon goals.**

- **Unmanaged adoption of all-electric heating solutions will likely induce significant increases in peak demand. Strategic electrification initiatives have the potential to help New York mitigate these impacts while still meeting the state's 2050 carbon goals.**
  - Increased adoption of dual-fuel heat pumps: 22.4% reduction in peak demand compared to an unrestricted all-electric scenario
  - Increased adoption of all-electric, high-efficiency heat pumps: 26.2% reduction in peak demand compared to an unrestricted all-electric scenario
  - Adoption of all-electric heat pumps, sized for heating: 9.7% reduction in peak demand compared to an unrestricted all-electric scenario

- Rising peak demand due to electrification in NY State will require capital investment for electric utilities in new transmission and distribution infrastructure. A sensitivity analysis of peak demands was performed to account for severe weather impacts that may be seen in the future. Based on this analysis, it is seen that winter peaks are expected to be more sensitive to severe weather conditions than corresponding summer peaks based on the inherent operating characteristics and relative performance of heat pump systems. **For building electrification, this analysis reinforces the need for reevaluating the electric system design standard to ensure system reliability in severe winter weather conditions.**

- **While advances in heat pump technology and increased awareness of the state's carbon policies help shift the market from fossil fuels toward electrified end-uses, electrification of building heating will ultimately depend on individual customer decisions unless there are strong mandates to adopt heat pumps.** Even in the presence of mandates, advancing building electrification by accelerating specific types of heat pump technology adoption will rely on considerations such as market readiness, technology maturity, vendor-to-customer education, and cost.

SECTION 1: INTRODUCTION

1.1 Background and Objective

New York State has set ambitious goals to address climate change by neutralizing its volume of anthropogenic emissions. New York's Climate Leadership and Community Protection Act (CLCPA) commits the state to reducing economy-wide greenhouse gas emissions 40% by 2030 and no less than 85% by 2050 compared to 1990 levels [1]. Meeting this goal depends on utilities encouraging consumers to adopt energy efficient and low-carbon emitting technologies.

From 2017 to 2019, Consolidated Edison Company of New York, Inc. (Con Edison), the New York Power Authority (NYPA), and the New York Independent System Operator (NYISO) contracted with EPRI to conduct the study "Electrification Scenarios for New York's Energy Future" [2], which aimed to analyze the potential role of electric technologies in buildings, industry, and transportation end-uses. Specific to building electrification, the 2017–2019 study analyzed the technical performance of electric heat pumps and impact of implementing electric heat pumps to help meet the state's energy needs. It found that baseline air-source heat pumps meet heating needs at moderate temperatures (above 35°F) but require supplemental heating by electric resistance, gas furnace, or oil-based equipment at lower temperatures. Because the study occurred before CLCPA enactment, it did not provide policy recommendations, nor did it identify specific pathways to achieve the state's greenhouse gas (GHG) targets. Instead, it recommended considering the following aspects of building electrification:

- Identify more-efficient pathways to achieving energy goals in building heating. Specifically, explore the feasibility of implementing a wider range of advanced heating technologies, such as next-generation heat pumps, geothermal heat pumps, and hybrid or dual-fuel systems.
- Analyze the relationship between building envelope energy efficiency measures and heating options, then assess the benefits and costs of retrofit applications.
- Gain insight into how changes in climate conditions combined with different energy use patterns impact peak demand.
- Assess the role and value of energy storage, demand response, and other grid flexibility options to manage future peaks.

The current work builds upon the 2017 study by bringing together the utility stakeholders—Consolidated Edison Company of New York, Inc. (Con Edison), the New York Power Authority (NYPA), New York Independent System Operator (NYISO), and Central Hudson to analyze building space heating electrification solutions available to New York residents and businesses and their impacts in detail. EPRI also involved the New York State Energy Research and Development Authority (NYSERDA) in a consultation role. This study also performs a review of actual field observed heat pump data to better understand heat pumps' real-world performance. Additionally, this study helps the stakeholders gain clearer insights into design considerations for installation, operation and maintenance of heat pumps.

1.2 Study Approach and Methodology

The main focus of this study is to provide an in-depth understanding of the electrification opportunities and considerations associated with implementing heat pumps for building space heating. The study employs industry standard models and approaches to examine the energy consumption of various electric and baseline space heating systems for specific building typologies. The project team obtained annual and hourly energy consumption estimates by simulating the operation of heat pump systems in buildings using the U.S. Department of Energy's (DOE's) EnergyPlus software [3], which has a well-established library of heat pump performance curves—capacity and coefficient of performance (COP)—that can be used to run simulations. EnergyPlus built this library of curves based on a detailed review of manufacturer-expanded performance data and their compilation into a usable format. The team also gathered and analyzed heat pump performance data for cold climate zones to understand their performance variation in the field. The resulting differences between the field performance of heat pumps and the results modeled by standard EnergyPlus curves are documented in this report. By including field-observed data, this study is expected to better reflect real-world heat pump performance scenarios for buildings.

This study also models the lifecycle costs, peak demand impacts, and carbon dioxide (CO_2) emissions of heat pumps compared to alternative systems for various residential and commercial building typologies. These results are reported with and without adjustments for building envelope improvements.

Following the analysis of individual heat pump types for specific building typologies, the team conducted a market evaluation of building heating electrification by modeling various heating pathways (scenarios) through to 2050. This was accomplished through EPRI's modeling framework that predicts the final energy consumption, carbon emission reduction, and demand impacts for residential and commercial heating in buildings across New York State. Performance of heat pump technology for space heating (in terms of COP and cycling losses) is assumed to improve over time. For air-source heat pumps, a gradual transition from a single-speed technology to more efficient heat pump technology is considered. For geothermal heat pumps, the heating efficiency is assumed to improve over time as a result of heat-capture technology improvements. Additional details on technology assumptions are presented in Section 5.

To increase the precision of the market evaluation model, the team placed significant emphasis on accurately determining the baseline estimates of current energy consumption and load shapes for building end-uses in New York State. The current building stock, floorspace, and technology saturation assumptions employed in EPRI's modeling framework are aligned with available end-use surveys from NYSERDA, namely the Residential Building Stock Assessment [4], Residential Statewide Baseline Study [5], and Commercial Statewide Baseline Study [6]. EPRI utilized these data sources/surveys to improve on the limited geographic granularity of the RECS [7] and CBECS [8] databases provided by the Energy Information Administration. For weather dependent end-uses, hourly meteorological data from NREL's National Solar Radiation Database [9] is utilized along with gridded population data from Columbia University's Socioeconomic Data and Applications Center [10] to capture the impact of variations in climate at a sub-state level. Due to their importance with regard to future peak impacts, space heating and space cooling are modeled in greater detail than other end uses.

The insights brought forward from this analysis offers a comprehensive assessment of electrification potential of building energy end-uses in NYS, including opportunities and challenges associated with various pathways. This research will help the energy system stakeholders (energy utilities) explore strategies for clean energy across a set of scenarios.

SECTION 2: ENERGY, SIZING AND EMISSION CHARACTERISTICS OF HEAT PUMPS

2.1 Types of Heat Pumps

Heat pumps for space heating are an effective vehicle for decarbonization as they displace the use of fossil fuels and eliminate on-site emissions. Heat pumps also provide a clean source of energy when the generation mix is heavily based on renewable sources. To understand the potential of electrification in the buildings sector, EPRI conducted a detailed engineering assessment of building heating technologies and fuels, along with their applicability to ducted and non-ducted New York buildings. The types of heat pumps analyzed for this study are air-source heat pumps, cold-climate air-source heat pumps, geothermal heat pumps, dual-fuel heat pumps, ductless/variable refrigerant flow (VRF) heat pumps, and rooftop heat pumps.

The most common air-source heat pumps sold and installed in the U.S. residential sector today have efficiency levels ranging from 120–300% in winter [11]. The marginal efficiency (the rate of heating energy produced per unit of energy consumed) depends on the amount of local, ambient heat that can be extracted from the air. While heat pumps with single-speed compressors are more common nationwide, the heating capacity of these standard-efficiency air-source heat pumps degrades severely when the outdoor air temperature falls below about 30°F (-1°C) [12], so the colder months of the year require supplemental heat from a less-efficient heating source, such as electric resistance or a natural gas furnace.

To address this challenge and help increase heat pump adoption in northern U.S. climates, multiple manufacturers have developed cold-climate air-source heat pump models that operate with variable speed compressors and are well-suited to provide heating in New York's climate. For residential-sized heat pumps, cold-climate air-source heat pumps are now widely available in both ducted and ductless (mini-split or multi-split) products [13]; these models meet industry-recognized specifications [14, 15] for high-efficiency performance and adequate heating capacity at 5°F (-15°C) and below. Comparable specifications and models do not yet exist for cold-climate air-source based packaged rooftop units (RTU) and split-system products in light commercial capacities, though such commercial products are emerging. Research initiatives such as DOE's recent cold-climate heat pump challenge [16] are additional market enablers to increase cold-climate heat pump penetration.

The current work quantifies the heating capacity and efficiency of different heat pumps and compares their performance with natural gas heating, ventilation, and air conditioning (HVAC) equipment used for space heating. The heat pumps and alternative systems selected for this analysis are shown in Table 1 and Table 2. The residential HVAC systems (Table 1) are modeled for a single-family home and a multi-family building, while the commercial HVAC systems (Table 2) are modeled for a large office building. Details about the modeled building typologies are provided in Figure 1, Figure 2, and Figure 3. The team utilized the SEER, HSPF and COP values reported in Table 1 and Table 2 to choose from the HVAC system performance curves available in EnergyPlus [17], which were then used to perform annual simulations of hourly heating and cooling loads, along with resulting energy usage.[4] Note that the performances of these heat pumps are based on current performance levels. Improvements to heat pump performance levels in future are accounted for as part of market evaluation (Sections 5 and 6 of this report).

4 Many of the default performance curves available in EnergyPlus are based on manufacturer's expanded product data tables. To provide more credibility to the results of this study, the performance of heat pump systems shown in this section have been verified using field tested data results. Those results are described in Section 4.

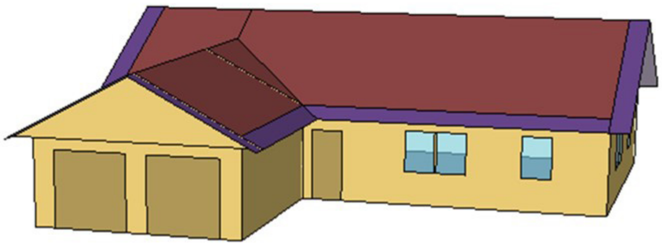
Table 1. *Types of residential HVAC systems modeled*

RELEASE	BACK UP HEAT SOURCE	COOLING EFFICIENCY	HEATING EFFICIENCY	BACKUP HEAT EFFICIENCY	CROSS-OVER TEMPERATURE	SOURCE OF EQUIPMENT SPECIFICATIONS
Air-source heat pump	Resistance	14.0 SEER	8.2 HSPF	95%	35°F	Manufacturer certified efficiency based on U.S. DOE Minimum Efficiency Standard [18]
Dual-fuel heat pump	Natural gas	14.0 SEER	8.2 HSPF	80%	35°F	
Cold climate heat pump[3]	Resistance	21.0 SEER	13.0 HSPF	95%	5°F	Market review of available products in the market and their manufacturer rated efficiency levels
Ductless mini-split heat pump	Resistance	20.0 SEER	11.0 HSPF	95%	5°F	
Geothermal heat pump	None	30.0 SEER	15.7 HSPF	NA	NA	
Window AC + gas boiler	None	14.0 SEER	95%	NA	NA	Cooling Efficiencies match corresponding minimum heat pump SEER values
Central AC + gas furnace	None	14.0 SEER	95%	NA	NA	

3 In this report, the term cold climate heat pump has been used as an equivalent for a ducted system. However, many models of ductless heat pumps will also classify as "cold climate" as per the NEEP Cold Climate Air Source Heat Pump specifications. Ductless heat pumps have been categorized separately to help understand specific considerations involved in replacing existing non-ducted fossil fuel HVAC systems.

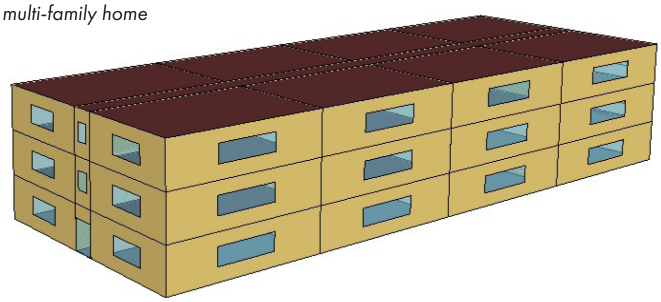
Table 2. Types of commercial HVAC systems modeled

RELEASE	BACK UP HEAT SOURCE	COOLING EFFICIENCY	HEATING EFFICIENCY	BACKUP HEAT EFFICIENCY	CROSS-OVER TEMPERATURE
Rooftop heat pump	Resistance	12.7 IEER	3.3 COP (at 47°F)	95%	35°F
VRF heat pump	Resistance	13.0 SEER	3.4 COP (at 47°F)	95%	5°F
Geothermal heat pump	None	4.5 COP	3.6 COP	NA	NA
Packaged gas rooftop unit	None	12.7 IEER	80%	NA	NA
Boiler + chiller	None	12.7 IEER	80%	NA	NA



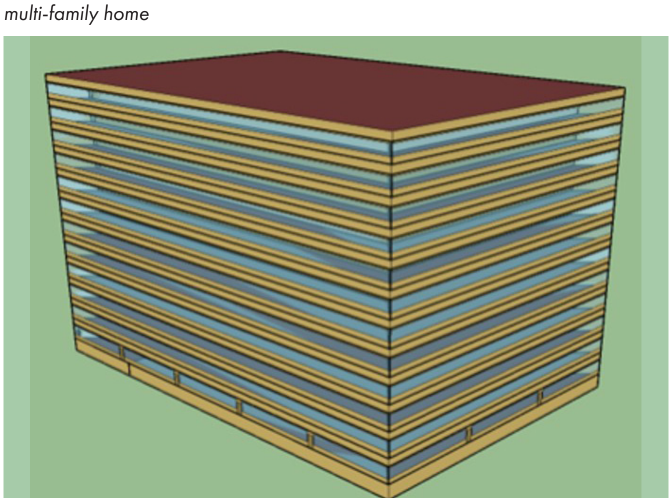
NUMBER OF BEDROOMS	NUMBER OF BATHROOMS	CONDITIONED AREA	UNCONDITIONED AREA	TOTAL AREA
3	2	1500 ft^2	400 ft^2	1900 ft^2

Figure 1. Building model and parameters used for energy modeling of a multi-family home



NUMBER OF FLOORS	NUMBER OF HOUSING UNITS	CONDITIONED AREA	UNCONDITIONED AREA	TOTAL AREA
3	24 (1000 ft^2 each)	25,500 ft^2	0 ft^2	25,500 ft^2

Figure 2. Building model and parameters used for energy modeling of a multi-family home



NUMBER OF FLOORS	NUMBER OF BATHROOMS	CONDITIONED AREA	TOTAL AREA
12+ basement	498,600 ft^2	0 ft^2	498,600 ft^2

Figure 3. Building model and parameters used for energy modeling of a large office building

2.2 Annual Energy Performance of Heat Pumps and CO_2 Reduction Potential

Though New York State spans a large geographic area with multiple climate zones, the detailed energy and CO_2 analysis presented in this section is specific to New York City (American Society of Heating, Refrigerating and Air-Conditioning Engineers—or ASHRAE—Climate Zone 4A) for the sake of consistency and brevity. (A separate subsection is included at the end of this section to show the sensitivity analysis for Upstate New York.) For an existing 1500 ft^2 single-family home in New York City, single-speed air-source heat pumps with resistance backup and dual-fuel heat pumps (with supplemental heating when outdoor temperatures fall below 35°F) should be sized to about 4 tons of capacity to meet heating and cooling needs for a typical design day. To meet New York City design temperatures without supplemental heating capability, high-efficiency geothermal heat pumps and cold-climate ductless mini-split heat pumps also should be sized to about 4 tons of capacity, while a ducted cold climate air-source heat pump would need to be larger (about 5 tons). A single-speed air-source heat pump with no backup would need to be sized to 6 tons to provide adequate heat to occupants. Within the same heat pump specifications, individual 2-ton heat pumps of distinct types can meet the heating needs of a three-story apartment building with total conditioned space of 25,500 ft^2 (24 housing units). Packaged rooftop heat pumps or VRF heat pumps are the primary heat pump configurations used in commercial buildings. The heating requirement of large commercial buildings can be met by rooftop heat pumps, VRF heat pumps, or geothermal heat pumps with 6.5–8.5 W/ft^2 of heating capacity.

Figure 4, Figure 5, and Figure 6 show the annual energy consumption of heat pumps in various building typologies. Heat pumps meet the annual heating and cooling requirements by consuming 4-6 kWh/ft^2 of electricity per year for single-family home (including any supplemental heat). The corresponding energy intensity is lower for larger buildings, such as multi-family (2.5–3.5 kWh/ft^2) and commercial buildings (3.6-5.5 kWh/ft^2), owing to their nature of internally dominated building loads, which contribute to increasing the cooling loads and consequently reducing the heating loads. (Note that this behavior is exhibited only for the climate of New York City and not the colder climates in Upstate New York, as is shown in Section 2.4.) The annual electrical energy use for heat pumps also depends on the cross-over temperature of a supplemental heating system and the type (electric or gas) of supplemental heat. Many times, HVAC contractors size heat pumps for cooling load and not for the heating load because oversizing of fixed speed heat pumps are not permitted or severely restricted by codes and standards. [19] As a result, a robust supplemental heating system is needed in the heating mode. Considering the use of supplemental heating is critical for this analysis because it affects the annual heating efficiency of the heat pumps. Table 3 shows the efficiencies at which various heat pumps operate over the course of the annual heating and cooling seasons in different building types. The heating COP roughly varies from 1.2–3.4 for various heat pumps. Cold-climate heat pumps and ductless heat pumps have greater operational efficiencies than single-speed air-source heat pumps with resistance backup, natural gas backup, or no backup. For example, the heating efficiency of cold-climate heat pumps and ductless heat pumps are 10–20% higher than an air-source heat pump with resistance backup in single-family home. Geothermal heat pumps have the highest annual heating COP in all building types (3.38 for single-family homes, 2.92 for multi-family buildings, and 3.46 for commercial buildings) while dual-fuel heat pumps have the lowest annual heating COP in residential homes (1.39 for single-family homes and 1.83 for multi-family homes) due to the natural gas backup operating at efficiencies lower than 100% for a considerable amount of runtime when the outdoor air temperature falls below 35°F. Finally, the operation of various air-source based heat pumps in residential buildings have higher efficiencies than commercial heat pump types, such as rooftop heat pumps and VRF heat pumps. There are very few cold climate heat pump systems for commercial buildings with higher operating performance (i.e. increased seasonal efficiency and increased efficiency at lower outdoor air temperatures) and they have not been evaluated through this modeling exercise due to lack of sufficient data. For the state of New York, NYSERDA and partners are advancing a "Resource Efficient Electrification (REE)" approach [20],[5] which describes a reducing heating loads, integrating heat recovery, and reconfiguring the HVAC distribution system before installing a "right-sized" heat pump (noting that technology will improve).

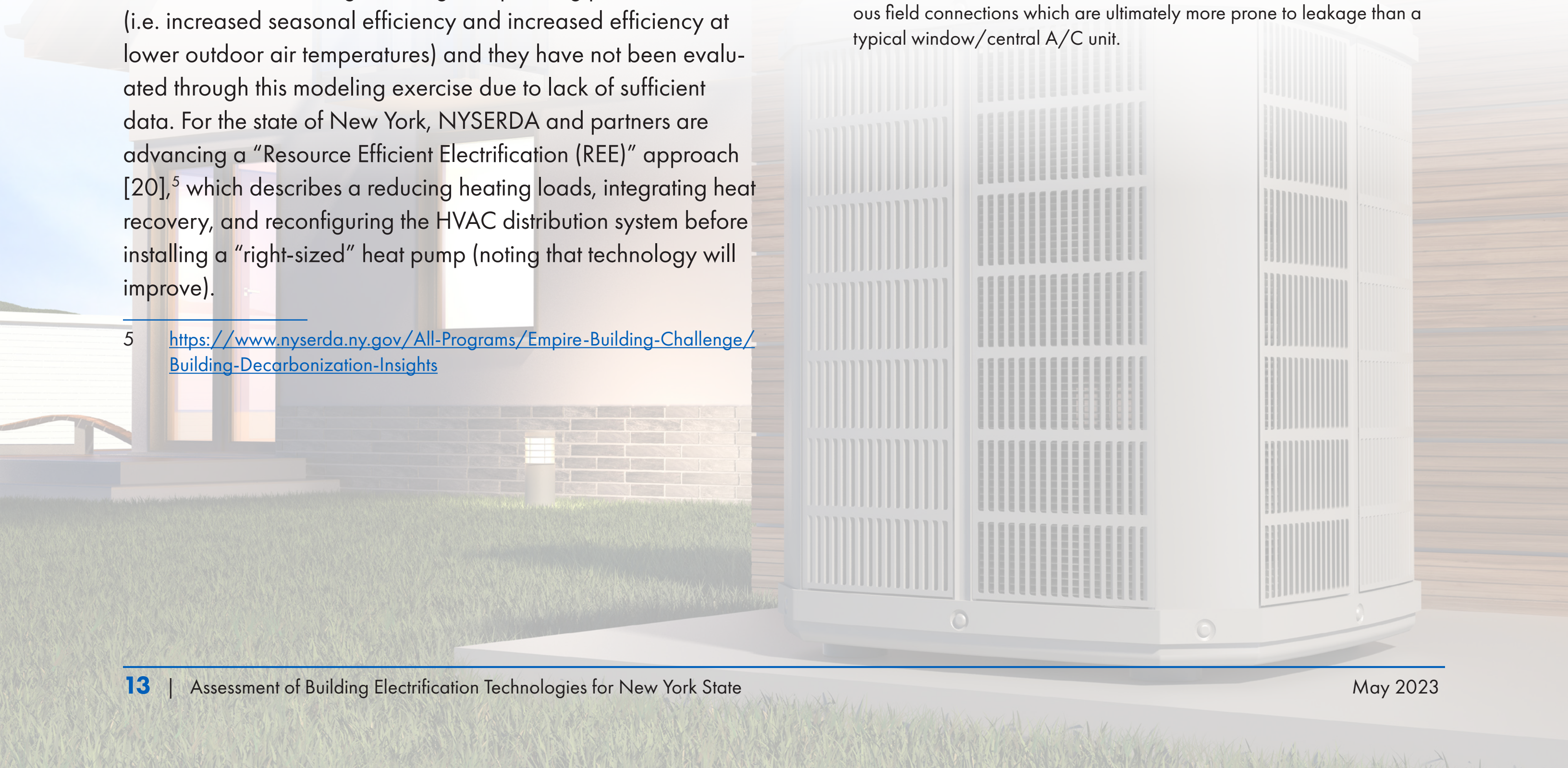
5 https://www.nyserda.ny.gov/All-Programs/Empire-Building-Challenge/Building-Decarbonization-Insights

Impact of improved building envelope on heat pump sizing and performance: The above-mentioned equipment sizing and annual energy consumption is lower for newly constructed buildings with improved building envelopes due to the adoption of stricter codes for building insulation. Better insulation lowers heat transfer across the building envelope, which results in increased operational heating efficiency. The annual energy requirement for new buildings was calculated using the New York State Energy Conservation Code Standards [21], and was found to be 10–18% lower than those of existing buildings, making it possible to reduce the planned heat pump size (by 1 ton for single-family homes and 0.5 tons per apartment in multi-family homes). Building envelope improvements therefore reduce the overall cost of heat pump installation and operation. This is further outlined in Section 3, where HVAC system costs are described.

Carbon emission reductions are realized by both electric and dual-fuel heat pumps relative to fossil fuel alternatives. Figure 7 shows that the marginal emissions [6] of nearly all types of heat pumps for all building types are lower than natural gas-based heating systems. The annual improvement rates on marginal emissions are ~15% compared to natural gas systems, depending on the specific heat pump technology. The carbon emission comparisons shown in Figure 7 are based on operation of the equipment and do not account for the carbon emissions resulting from refrigerant leakage during installation.[7]

6 For the results shown in this section, CO_2 emissions of electric and natural gas systems were compared and calculated using a marginal CO_2 emission factor of 0.88 pounds per kWh for electricity and 117 pounds per MMBtu for natural gas.

7 Although the installation of a heat pump would most likely be the replacement of other HVAC equipment that contains refrigerant, the nature of the install may be more susceptible to refrigerant leakage. For example, mini-split system installs rely on the technician/homeowner to make numerous field connections which are ultimately more prone to leakage than a typical window/central A/C unit.



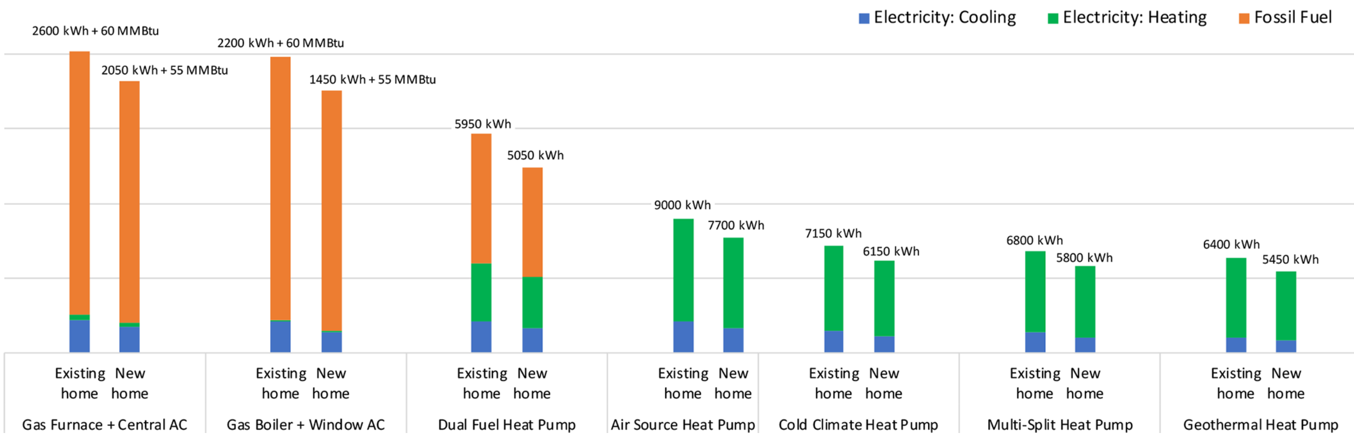


Figure 4. *Energy performance of HVAC systems for a single-family home in New York City, NY*

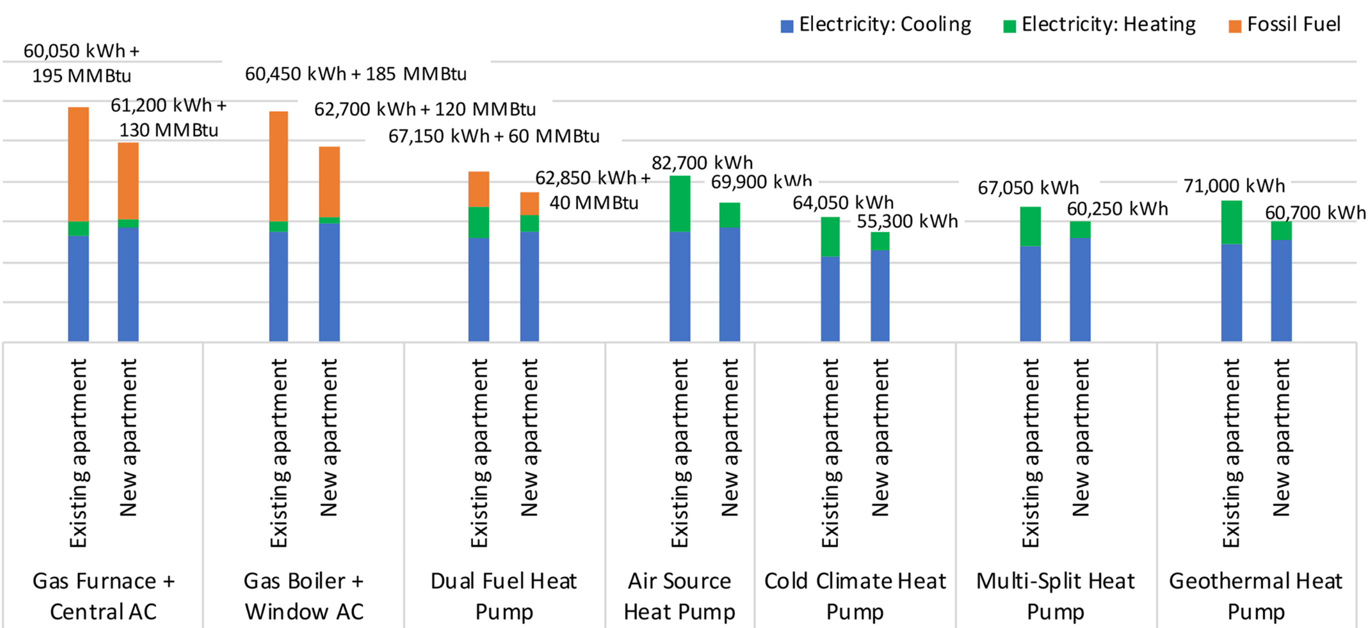


Figure 5. *Energy performance of HVAC systems for a multi-family home in New York City, NY*

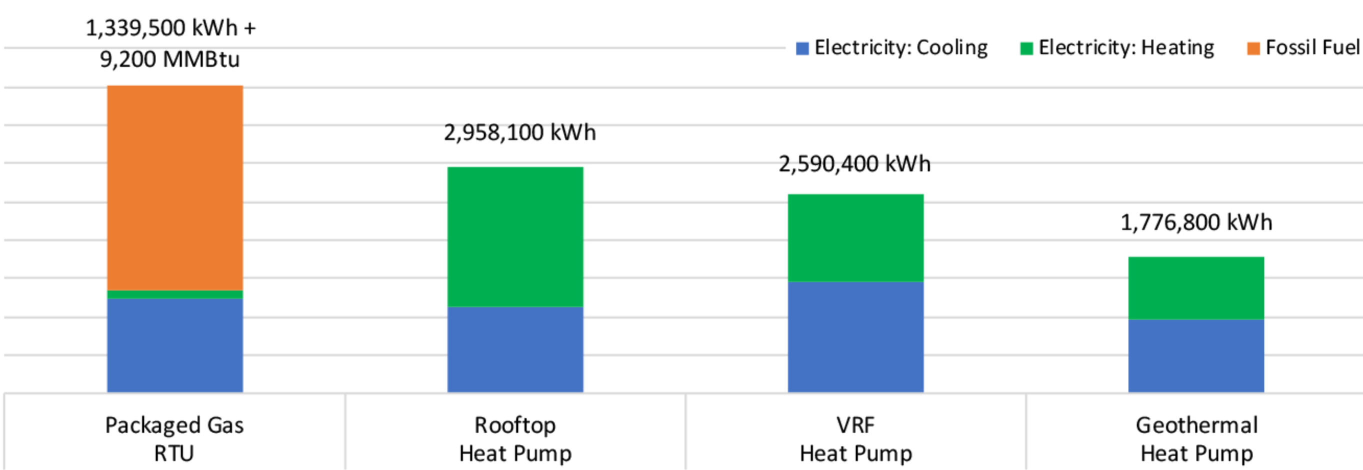


Figure 6. *Energy performance of HVAC systems for large office building in New York City, NY*

Table 3. Modeled efficiencies of heat pump systems in New York City, NY[8]

BUILDING TYPE	HEAT PUMP TYPE	AVERAGE HEATING COP	AVERAGE COOLING COP
Single-family home	Air-source heat pump with resistance backup	2.61	3.08
	Ductless heat pump	2.87	4.59
	Cold-climate heat pump	3.19	4.82
	Geothermal heat pump	3.38	5.85
	Dual-fuel heat pump	1.39	2.42
	Air-source heat pump with no backup	2.05	2.85
Multi-family home	Air-source heat pump	1.94	2.81
	Variable capacity heat pump	2.25	3.28
	Ductless split heat pump	2.56	3.54
	Cold-climate heat pump	2.62	3.64
	Geothermal heat pump	2.92	3.14
	Dual-fuel heat pump	1.83	2.78
	Air-source heat pump with no backup	1.79	2.79
Large office building	Rooftop heat pump	1.23	3.39
	VRF heat pump	1.99	2.61
	Geothermal heat pump	3.46	3.91

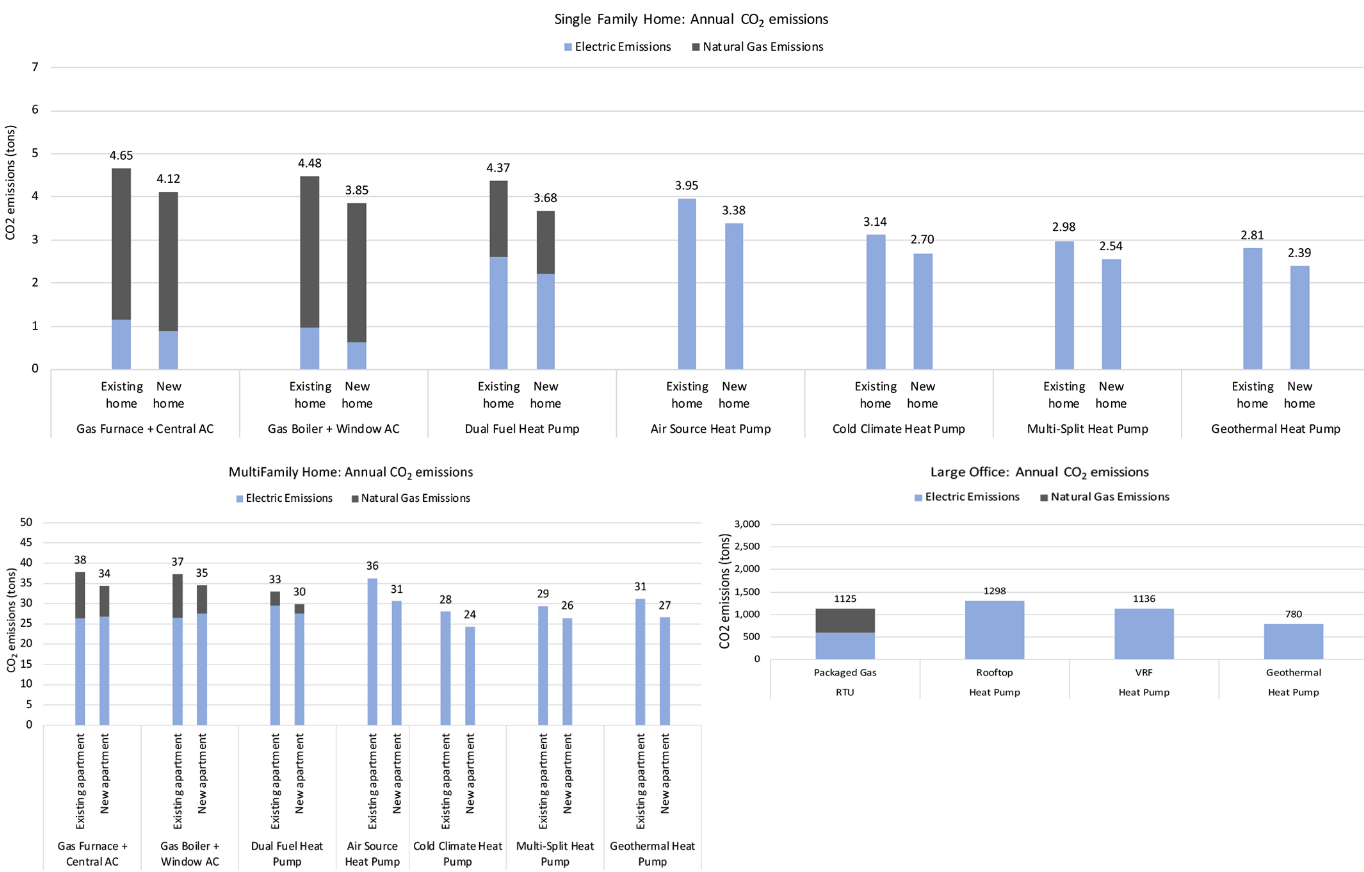


Figure 7. Annual CO_2 emissions of different HVAC systems for different building typologies in New York City, NY.
Note: *Marginal emission factors for 2022 electricity generation was used.*

8 These efficiencies are based on building modeling for New York City region, and would be different for upstate region. The performance of heat pumps in upstate New York is discussed in Section 2.4.

2.3 Operating Efficiencies and Electricity Demand of Heat Pumps at Lower Outdoor Air Temperatures

While the efficiencies of various heat pumps described in Section 2.2 relate to the annual heating season, an electric utility is normally concerned with a customer's energy use and peak demand during the coldest weather. Table 1 shows that, for the building energy simulations performed under this study, air-source heat pump with resistance backup had a cross-over temperature of 35°F. This is the temperature below which the back-up (supplemental) heat source started operating. In comparison, the cold-climate heat pump and the ductless heat pump had a cross-over temperature of 5°F. The peak demand and COP observed under these conditions for various heat pumps during peak demand are shown in Table 4 for residential buildings (single-family and multi-family buildings) and in Table 5 for large commercial office buildings. Table 4 also includes the peak demand and COP for an oversized single speed air source heat pump with no backup. The oversized air source heat pump is sized larger than the cold-climate heat pump, as a result of which it is able to use solely heat pump mode at the peak condition with no backup. However, oversizing a single-speed heat pump would impact the summer cooling operation of the heat pump through short-cycling and the inability to maintain humidity at the desired level.

2.3.1 *Insights on Heat Pump Efficiency and Demand at Lower Outdoor Air Temperatures for Single-Family Home*

The Typical Meteorological Year (TMY3) [22] weather data for New York City showed that during the coldest hours of the year—which occurred during the 8-hour period between February 5, 11:00 p.m. and February 6, 7:00 a.m.—the outdoor temperature varied between 5–7°F. During this period, EnergyPlus simulations showed that the house had a heating load of 50,000 Btu/h. That amount of heat could have been supplied by an electric resistance heater with an electricity peak demand of 14.9 kW. In comparison, the air-source heat pump with resistance backup had a peak demand of 9.82 kW. The air-source heat pump's COP while suppling peak heating demand was 1.4, which included the combined operation of the heat pump and the resistance backup. This heating COP at winter peak for the air-source heat pump with resistance backup is nearly half of its annual heating season average COP value of 2.61 over the entire heating season.

The cold-climate heat pump and ductless multi-split heat pump showed a greater COP during peak heating hours and correspondingly, a lower peak demand. The cold-climate heat pump had a COP of 1.63[9] and the multi-split heat pump had a COP of 1.97 during the peak hour of heating load. These values are 12% and 44% greater than the COP of the air-source heat pump with resistance backup at peak heating condition. This increase is due to the higher operating efficiency assumptions for these two types of heat pumps, which are modeled with a cross-over temperature of 5°F. Therefore, at peak heating load conditions, both the cold-climate heat pump and multi-split heat pump could operate with minimal amount of resistance heat at/below the cross-over point. Additionally, the multi-split heat pump benefited from having no duct losses, which resulted in additional increase in COP. However, both these heat pumps were sized about a ton higher than the air-source heat pump to meet the heating load without using resistance backup at the cold temperatures. Accordingly, the peak demand values for the cold-climate heat pump and multi-split heat pump at the coldest temperatures were lower than the air-source heat pump with resistance backup.

9 It should be noted here that the COP reported for the cold-climate ASHP is based on the modeling of a specific model of a heat pump that satisfies the SEER and HSPF values in Table 1. Other studies (e.g. NYSERDA's BEEM model [23]) have modeled higher COP for the peak conditions.

Table 4. *Heating efficiencies of heat pumps at peak conditions for residential building types*

HEAT PUMP TYPE	SINGLE-FAMILY HOME		MULTI-FAMILY BUILDINGS	
	PEAK HEATING KW	COP AT PEAK AT 5°F	PEAK HEATING KW	COP AT PEAK AT 5°F
Air-source heat pump with resistance backup	9.82	1.4	78	1.2
Ductless heat pump	7.31	2.0	45	2.1
Cold-climate heat pump	8.67	1.6	56	1.9
Geothermal heat pump	5.07	2.8	34	2.7
Air-source heat pump with no backup	8.07	1.7	55	1.7

Table 5. *Heating efficiencies of heat pumps at peak conditions for large office building*

HEAT PUMP TYPE	PEAK HEATING KW	PEAK COP
Rooftop heat pump	3210	1.1
VRF heat pump	1835	1.8

The team also simulated an oversized air-source heat pump—with an additional 2 tons of heating capacity and no resistance backup—to understand the impact of eliminating resistance heating completely. The air-source heat pump with no backup showed a peak demand of 8.07 kW and a COP of 1.72 at this peak heating load condition. Compared to the air-source heat pump with resistance backup, this peak demand is 18% lower and the COP at peak demand is ~25% higher. To avoid the cost to consumers of building out the electric system to potentially meet an extreme electric heating peak, it can be beneficial for customers to oversize their heat pumps to reduce system demand on the peak day. However, from a customer's perspective, this would result in a higher upfront cost.

The geothermal heat pump had the lowest peak demand among all the heat pumps simulated. The peak demand to meet the single-family home load during the coldest period was 5.07 kW, which is accomplished at a COP of 2.8. Notably, the COP of heat pumps using outside air as the heat source during peak conditions is significantly lower than their average COPs during the entire heating season, but the same comparison for the geothermal heat pump reveals a much lower difference. While the COPs for all air-source heat pump systems depend on outside air temperature to collect and disperse heat, ground-source heat pumps that rely on the steadier ground temperatures to extract (or reject) heat are much less affected by cold (or warm) climates and produce heating (or cooling) at a much steadier COP in various climates.

Finally, the dual-fuel heat pump (not reported in Table 4) has a lower peak electricity consumption than the electric heat pumps. Its heat pump mode is set to completely disengage when temperatures fall below 35°F, leaving only the fossil fuel heater operating, so its peak electricity consumption occurs at around 35°F. The peak demand value of 3.08kW and the corresponding COP of 2.26, are higher than the COPs at peak heating for all-electric air-source heat pumps (due to the dual-fuel heat pump peak occurring at a much higher temperature), but lower than the COP at peak heating for the ground-source heat pump. In other words, dual-fuel heat pumps can be viewed as a peak demand-shaving interim technology, with an electricity peak demand falling between the various air-source based heat pump types and the geothermal heat pump.

2.3.2 Insights on Heat Pumps Efficiencies and Demand at Lower Outdoor Air Temperatures for Multi-Family and Commercial Buildings

Compared to single-family homes, the simulation results for multi-family homes and commercial buildings reported in Table 4 and Table 5 show similar trends for variation in COP at peak heating condition between different heat pump types. Specifically, the air-source heat pump with resistance backup has the lowest COP (1.20 at peak heating condition), while the geothermal heat pump has the highest COP (2.70 at peak heating condition). Accordingly, the peak demand value of 78 kW is highest for the air-source heat pump with resistance backup, while the more efficient heat pumps (cold-climate heat pumps and multi-split heat pumps) have a peak demand that is up to 42% lower. The peak demand of the geothermal heat pump is approximately half of the peak demand of the air-source heat pump with resistance backup.

Rooftop heat pumps used for large offices are the closest "commercial" equivalent to residential air-source heat pumps with resistance backup. Rooftop heat pumps package the components into a single unit that is usually placed on the roof of a building. It draws in the return air from the space, then conditions and redelivers it to the space through ducts. In comparison, the VRF heat pumps are the "commercial" equivalent of the residential ductless multi-split heat pump. The rooftop heat pump's COP at peak heating conditions is 1.1 and the VRF heat pump's is 1.8, both of which are lower than their average heating COPs for the entire season.

Note that the peak demand results described in this section are for individual heat pump installations for different building typologies. The impact of heat pump usage on building peak demand at a state-wide level is analyzed in Section 6.

2.4 Heat Pump Energy Use in Upstate New York

To understand the differences in energy consumption patterns for HVAC systems in Upstate New York, the team performed a building energy simulation for an existing building located in Buffalo, New York (ASHRAE Climate Zone 5A [24]). It has the same multi-family building typology shown in Figure 2 and the same HVAC systems shown in Table 1. The results of this simulation are shown in Figure 8.

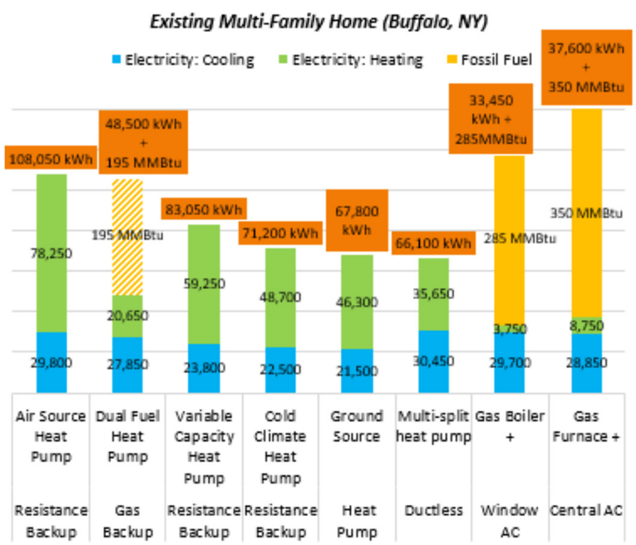


Figure 8. Energy performance of HVAC systems for a multi-family home in Buffalo, NY

Compared to downstate NY results in Figure 5, it is seen that for an existing 25,500 ft^2 3-story multi-family apartment in Buffalo, NY, heating requirements for HVAC systems are higher by 10-20% due to the colder winters. Specifically, because of colder winters, the ability of an air-source heat pump in Buffalo to meet the heating capacity is significantly reduced compared to New York City, and additional supplemental heat (electric resistance backup) is required, driving up the total electricity consumption and peak demand. Figure 8 shows that for the simulated multi-family building, the total electricity consumed for heating only by a single-speed air-source heat pump with electric resistance backup is 78,250 kWh, which is 1.70 more than a ground-source heat pump (46,300 kWh) that doesn't use any backup heat. The corresponding ratio between the annual heating energy consumption between a single-speed air-source heat pump with electric resistance backup and a geothermal heat pump with no backup for a downstate New York location was 1.27. That is to say, a heat pump with electric resistance backup consumes nearly 70% more energy than a ground-source heat pump in Buffalo, NY, due to its reliance on an electric resistance heat source at colder temperatures. On an average, heat pumps consume 2.5-4.5 kWh/ft^2 of electricity per year in this upstate NY location in order to meet the annual heating and cooling requirements for this building, which is higher than the range (2.5–3.5 kWh/ft^2) that was seen in upstate NY simulation results in Figure 5.

SECTION 3: HEAT PUMP ECONOMICS

3.1 Lifecycle Cost Determination

In this study, a cost analysis was performed by calculating and comparing the lifecycle costs of various heat pumps to the baseline natural gas-based heating systems, such as a central air conditioning/furnace combination and a window air conditioning/boiler combination. The lifecycle cost for new installations included the upfront installation costs and the operational (energy use) costs. For the new installations, material and labor costs—which together form the installed cost of HVAC equipment—were obtained from a construction cost database at a component-level [25], and were aggregated to obtain the total upfront cost. In comparison, replacing space heating systems in existing buildings requires additional cost to remove and recycle old equipment and replace ductwork if required. A cost breakdown for different categories of upfront costs considered are shown in Table 6.

To calculate the energy costs, the fuel prices provided by the study participants was utilized, and these in turn were based on 2020 fuel prices. Therefore, the lifecycle cost modeling is based on 2020 equipment and energy costs. A fifteen-year lifetime was assumed for all equipment.

3.1.1 Need for Electrical Upgrades

The cost for electrical upgrades is often hidden in the heat pump installation cost determination. Primary electrical additions to retrofit heat pump installations stem from the need to install an upgraded panelboard, including breakers and meter sockets, as well as ground and service entrance cables. These electrical hardware components can significantly increase the cost of retrofitting buildings with heat pumps. For residential buildings specifically, the electrical upgrade requirements are shown in Figure 9.

Table 6. *Cost assumptions used for HVAC equipment*

BUILDING TYPE	HVAC EQUIPMENT TYPE	EQUIPMENT COST RANGE ($/TON)	ACCESSORIES AND INSTALLATION CHARGES (EXCLUDES DUCTWORK)
Residential Buildings	Air Source Heat Pump	$2,000–$2,700	$1,500–$3,100 per ton
	Ground Source Heat Pump	$7,500–$11,200	
	Ducted Cold Climate Heat Pump	$2,800–$5,700	
	Ductless Multi-split Heat Pump	$3,500–$4,600	
	Central AC + Furnace	$1,800–$3,100	
	Window AC + Boiler	$2,300–$3,200	
	Dual Fuel Heat Pump	$2,400–$2,900	
Commercial Buildings	Rooftop Heat Pump	$4,000–$5,000	$750–$1,150 per ton
	VRF Heat Pump	$4,400–$6,800	
	Ground Source Heat Pump	$7,200–$11,000	
	Packaged Gas RTU	$2,600–$3,300	

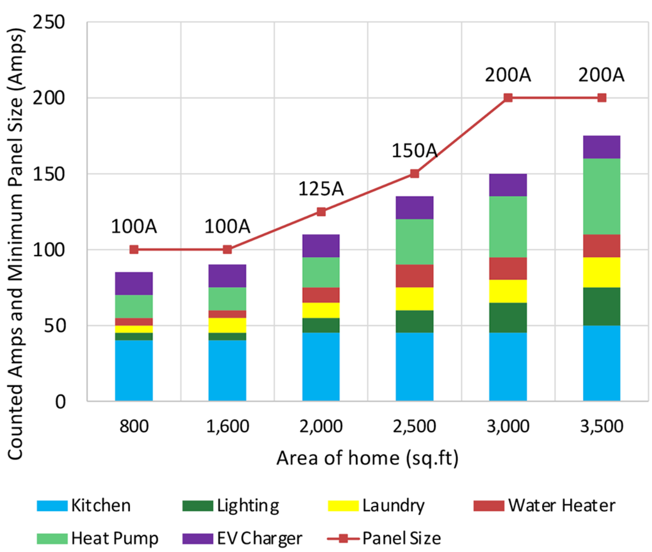


Figure 9. *Electrical service requirements for residential homes, adapted from [28].*

APPLIANCE	NATIONAL CIRCUIT REQUIREMENTS AND GUIDELINES	NEC REGULATION
Kitchen Counter Circuits	Two dedicated 20A circuits	NEC 210.52 (B)(1)
Kitchen Small Appliances	One or more additional circuits	
Range Circuit	Minimum of 40A	NEC 210.19 (3)
Bathroom Circuits	At least one 20A circuit	NEC 210.11 (C)(3)
General Lighting	3 Watts per sq.ft.	NEC 210.12
Other Large Appliances	Dedicated 15-50A circuit	
Note: A minimum of 100 Amp 3-wire service is required for a single-family dwelling unit. Source: National Electrical Code Guidelines [27]		

Electrical requirements for heat pumps are driven by the size of the heat pump needed to meet the home's heating load, which depends on the heated area. A more important driver for the electrical requirement of the entire home is the total number of electrical appliances being used (e.g., electrical water heaters, electric cooking ranges, electric vehicle chargers, etc.) and their cumulative electrical requirement. Whether a home will require a panel upgrade also depends on whether heat pumps use electrical resistance backup as opposed to fossil-fuel backup or no backup. Figure 9 shows the national electrical circuit requirements as per the National Electrical Code guidelines [26]. It also includes a guiding graph to illustrate that for larger homes, the sizing of electrical appliances may increase, which increases the total current supply requirement. Many single-family homes with 100A panel capacities will require electrical panel upgrades for heat pump installation. Whether a home will require a panel upgrade will depend on the other electrical end-uses in the home and if electric resistance backup is installed. The added cost of electrical upgrades is reflected in the customer's upfront cost premium, which ranges from $3,000–$8,000 per housing unit when including the cost of upgraded panel and related components and the cost of bringing additional electrical supply into the housing unit (which is sometimes borne by utilities). New construction homes and some existing homes would incur the cost of a new electrical permit.

3.2 Cost Comparisons of Heat Pumps with Natural Gas Heating Equipment

3.2.1 New Construction Buildings

Figure 10, Figure 11, and Figure 12 show the lifecycle cost of heat pump systems for new residential and commercial buildings when compared to natural gas-based heating systems. Generally, the lifecycle costs of heat pumps in residential single-family homes and large commercial office buildings are higher than the lifecycle costs of gas furnace and gas boiler-based heating systems. There are some exceptions in the case of multi-family buildings, where some air-source heat pumps appear to be more economical than natural gas alternatives due to the lower heat pump size per home required. (The cost of heat pumps scales upward more rapidly with increasing sizes than does the cost of gas furnaces and boilers.)

The results also show that air-source based heat pumps are more cost effective than geothermal heat pumps. While the latter, holds promise for significant reductions in energy consumption, carbon emissions, and peak demand (as shown in Section 2), the cost-effective adoption of the technology is significantly limited by higher upfront costs. Further, it can be inferred that because the cost analysis shows greater lifecycle costs for geothermal heat pumps than air-source heat pumps, installation of an appropriate air-source heat pump (i.e., an air-source heat pump with natural gas backup, or an oversized air-source heat pump with no resistance backup) could potentially provide a more economical heating option than geothermal heat pumps, while producing similar or lower peak demand.

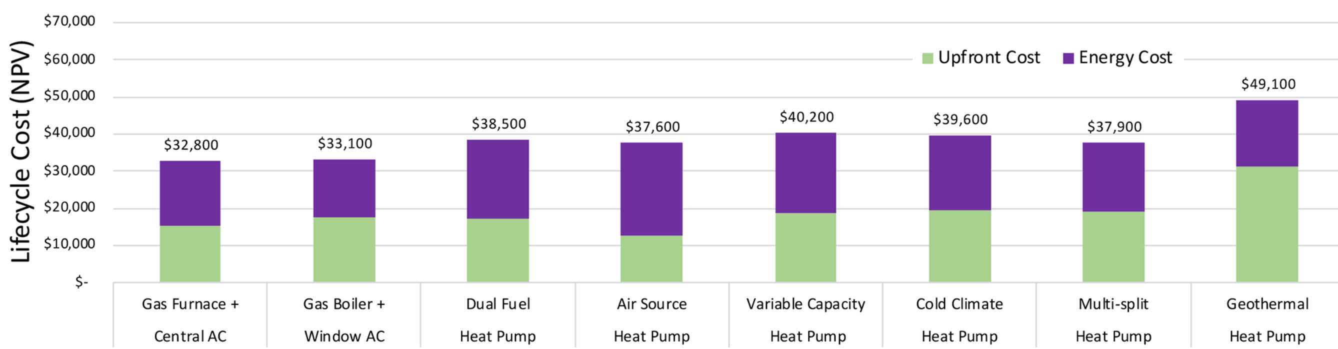


Figure 10. *Lifecycle costs of various residential heat pumps in a single-family home in New York City, NY, relative to natural gas-based heating systems.*

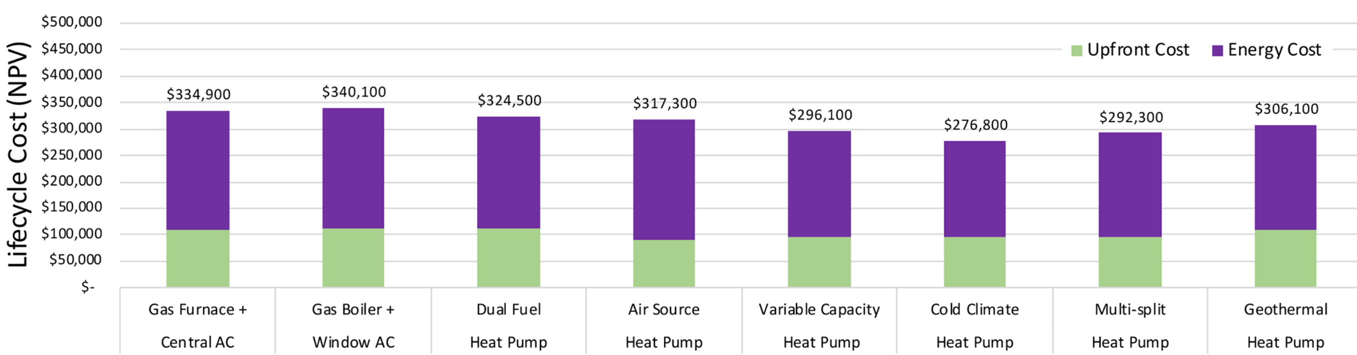


Figure 11. *Lifecycle costs of various residential heat pumps in a multi-family home in New York City, NY, relative to natural gas-based heating systems*

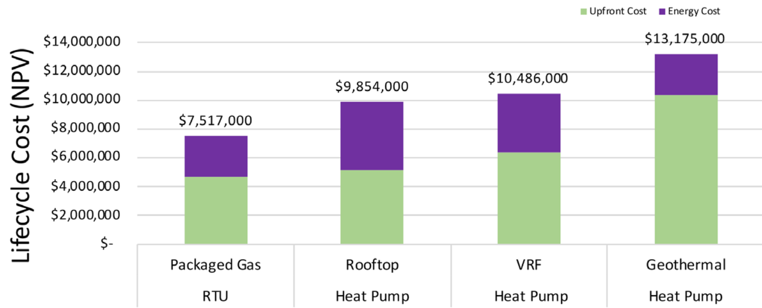


Figure 12. *Lifecycle costs of various commercial heat pumps in a large office building in New York City, NY, relative to natural gas-based heating systems*

3.2.2 Existing Buildings and Economic Impacts of Slack Building Envelope

Figure 13 and Figure 14 show the lifecycle cost of various residential heat pumps in existing single-family and multi-family buildings compared to natural gas-based heating systems. While all the HVAC systems considered under the cost analysis have been included in both these figures, ducted heat pumps are usually more suitable for replacing the gas furnace + central AC due to the presence of ducts, while the multi-split heat pump which is a ductless system is usually more suited to replace the gas boiler + window AC system which doesn't have ducts. Therefore the cost comparisons are best analyzed for these potential like-to-like replacements separately. For existing building construction, absent any incentives or rebates, the lifecycle costs of heat pumps are always higher than baseline fossil-fuel based heating equipment, irrespective of heat pump type. The only exception is seen for dual-fuel heat pumps appearing to be nearly the same or slightly lower cost than a gas furnace system. Key reasons for the higher lifecycle costs include higher upfront cost premium for various heat pump types (both air-source based heat pumps and geothermal heat pumps), as well as the added cost of retrofit components, including the customer's electrical infrastructure upgrade needs. It was assumed that dual-fuel heat pumps do not require an electrical upgrade unlike other ducted heat pump types retrofitted onto existing buildings, a reason why the former appears to be cost competitive than gas heating systems. Quantitatively, the increase in lifecycle cost for all air-source based heat pumps relative to natural gas equipment ranges 25–50% for existing single-family homes, 3–45% for existing multi-family buildings, and 30–40% for existing commercial buildings. When comparing the existing buildings with new building construction, the lifecycle costs of heat pumps decrease by up to 50% (15–25% higher cost for heat pumps than gas systems for new single-family homes and 3–17% lower than gas systems for new multi-family homes) for new buildings due to the improved building envelope. Note that new buildings can accommodate heat pumps with rated capacities 0.5–1 tons less than those typically installed in existing buildings, which reduces the equipment cost. For geothermal heat pumps, the lifecycle cost relative to natural gas equipment is 50–80% greater depending on building type.

Based on the economic analysis, the cost trends run counter to the energy usage and emission impacts of the heat pumps relative to the fossil-fuel based heating equipment described in Section 2. It should be noted that all lifecycle costs of electric heat pumps shown in this section have been presented with respect to natural gas HVAC systems. Oil or propane fired HVAC systems are obviously expected to have a higher lifecycle cost than natural gas systems due to the higher fuel costs, and in comparison to oil and propane systems, the electric heat pump options will be much more favorable cost-wise.

Understanding the cost trends of heat pump systems is important because electrification of building heating through heat pumps will depend to a large extent on individual customer decisions, of which economics is a key component. The higher lifecycle costs of heat pumps can be partially offset through rebates and incentives, which are not included in the cost data shown in Figure 10 through Figure 14, nor the inferences made on those figures in this section of the report. Of course, in addition to incentives, considerations such as market readiness, technology maturity, and vendor-to-customer education are also crucial to advancing building electrification through heat pumps.

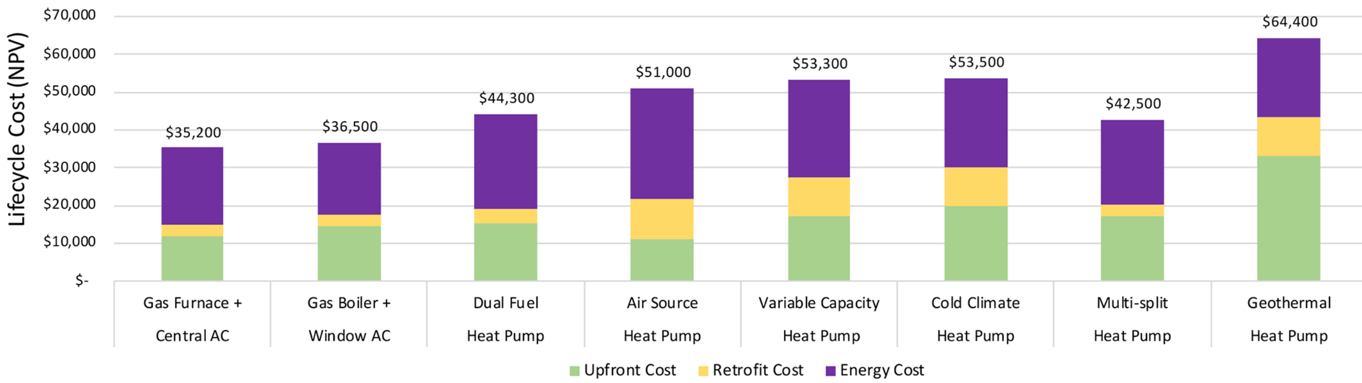


Figure 13. *Liifecycle costs of various residential heat pumps in an existing single-family building in New York City, NY, relative to natural gas-based heating systems*

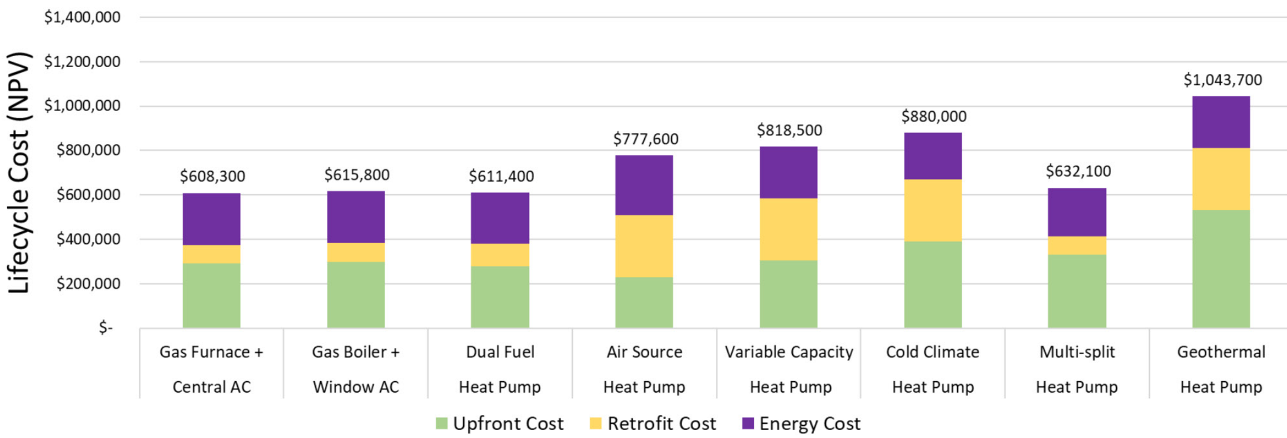


Figure 14. *Lifecycle costs of various residential heat pumps in an existing multi-family building in New York City, NY, relative to natural gas-based heating systems*

SECTION 4: FIELD STUDIES ON HEAT PUMPS

4.1 Purpose and Methodology of Field Data Analysis

The purpose of reviewing and analyzing field data as part of this study was to understand the typical energy usage and efficiency levels of heat pumps in the real world. Actual data can help model output parameters such as heating energy usage, equipment sizing, efficiencies, and demand.

The project team gathered studies from heat pump pilot projects conducted in northeastern U.S. areas that experience winter seasons either at the same level or more severe than those of New York State. The team reviewed the underlying data from these pilot studies—including field installation data for single-family homes, multi-family homes, and commercial buildings—to

(a) Confirm the true efficiency of heat pumps in cold climates

(b) Align energy use estimates for different heat pump types with modeling results

(c) Understand the existing practices on secondary heating in the field

(d) Understand heat pump sizing practices and sizing estimates

(e) Obtain an estimate of the observed demand for space heating

Over the course of the study, the team analyzed heat pump pilot data sets from four separate single-family home projects (cumulatively representing quantitative and qualitative findings from the field for 28 homes), four separate multi-family home projects (cumulatively representing quantitative and qualitative findings from the field for 48 apartments), and one commercial building project. A key goal of the study was to base the performance comparison with modeled studies on a reasonably adequate sample size—and while there was a larger sample size for residential buildings (single-family and multi-family homes), the sample size for commercial buildings was limited. The difficulty in obtaining information for commercial cold weather heat pump field pilots reveals a greater emphasis on field pilots for residential heat pumps than for commercial buildings. Additionally, the project team feels that there is need for more heat pump field data studies to be performed by the broad HVAC industry that report both pre-installation and post-installation performance data for heat pumps such as energy use, sizing practices, impact on peak demand, operating efficiency at cold weather conditions with and without the use of backup heat, and heat pump installation costs in order to better understand the field performance of heat pumps and ultimately better serve customers.

4.2 Evaluation of Heating Efficiencies from Field Studies

To gain confidence in the modeling results presented in Section 2, it is important to understand the heating efficiency of heat pumps in the field. Table 7 shows the consolidated quantitative data gathered from various field studies for single-family homes. (Note that not all of the pilot data sets collected had adequate quantitative data; some had only qualitative data. Only the studies with reliable quantitative data are included in Table 7.) It lists the pilot study name and location, the number of sites within each study, and the measured COP from the field. Table 7 also provides both seasonal average COP and COP at the coldest temperatures. Instead of directly reporting COP data, several of these studies included a graphical representation of COP variation against outdoor air temperatures. In such cases, the team digitized COP bin-hour and energy graphs to obtain more granularity and accuracy. Additionally, Table 7 shows the corresponding COP that would have been obtained with each of these field installations if the field site had been located in New York City. The team obtained these values through extrapolation of the original field measured COP to New York City weather, then compared them to the modeled COP for the heat pump type that most closely represents the one installed in the field. Unless specifically indicated otherwise, the COP values in Table 7 are inclusive of backup heating energy use, except for two sites in the Conservation Applied Research and Development (CARD), Minnesota study (2017) [29] that installed mini-split heat pumps without a backup heat source for the heat pump cycle. As part of the extrapolation process, the team made some adjustments to the field COP values to represent the building code standards used in the modeling as closely as possible. They also made approximations for certain samples in case the building code information for the building in the field was missing, or to account for missing heat pump seasonal efficiency values.

4.3 Insights from Field Data Analysis on Heating Efficiencies

Based on the limited sample size analyzed for different heat pumps (as shown in Table 7), the study calculated that field measured COPs exhibit an average of ~10% reduction compared to the modeled heat pump COPs. Heat pump efficiencies in the field depend on several factors, such as their operation style, occupant behaviors (e.g., temperature setbacks), and deterioration of equipment with age. Also, a portion of this difference can be attributed to the lack of complete information around several key parameters in the field pilot studies related to equipment specifications and building envelope, along with variations in climate zones between the pilot study location and the New York State climate. A current practice observed in the field is to size heat pumps for cooling. In a cold climate, a heat pump sized in this manner will fail to provide sufficient heating capacity. Sizing heat pumps for heating needs can prevent the need for backup heat, but comes at an additional cost.

Table 8 contains results for the multi-family heat pump field installations analyzed. Some of these field studies had only qualitative data regarding comfort aspects of heat pump operation. For example, one of the studies provided the insight that when ductless heat pumps are used, occupant comfort may be adversely affected if indoor units are not installed in every room or conditioned zone. The lack of separate indoor units may necessitate secondary heating. When using ductless heat pumps, secondary heating requirements will increase total energy consumption, although explicit quantitative measurements for primary versus secondary heating energy are unavailable.

The heat pump field studies gathered and analyzed as part of this study are generally more focused on energy use reduction. They are less informative on aspects of equipment costs and peak demand. There are isolated studies that provide directional alignment on peak demand of specific heat pump types. For example, one study [37] mentions that ductless heat pumps have more potential to reduce peak demand than a ducted heat pump with

Table 7. *Consolidated data for single family home pilot studies*

HEAT PUMP TYPE	NO. OF SITES	HEAT PUMP MOST CLOSELY REPRESENTING BUILDING MODEL	FIELD MEASURED COP (INCLUDING BACKUP HEAT)		HEAT PUMP COP EXTRAPOLATED TO NEW YORK CITY	MODELED COP FOR NEW YORK CITY	DIFFERENCE IN COP
			SEASONAL AVERAGE	AT COLDEST TEMPERATURES			
CEE (2018), St. Paul, MN [30]	1	Cold-climate	1.83	1.27 (-10°F<T<10°F)	3.70	3.08	-20%
NYSERDA (2013) Stuyvesant, NY [31]	1	Mini-split	1.9	1.5 @ 0°F	3.07	3.23	+5%
CARD, MN (2017) [29]	6	See individual sites below (sites 1–4 used propane backup. COPs include backup)					
Site 1		Cold-climate	2.18	0.93 (0°F<T<5°F) with backup 1.72 (9.15°F) without backup	2.43	3.08	21%
Site 2		Variable capacity	1.84	0.7 (-0.9°F) with backup 1.61 (6.48°F without backup)	2.33	2.77	16%
Site 3		Cold-climate	1.89	0.60 (0°F<T<5°F) with backup 0.95 (3.82°F without backup)	2.59	3.08	16%
Site 4		Cold-climate	2.50	0.82 (0°F<T<5°F)	3.14	3.08	-2%
Site 5		Mini-split	2.19	1.76 (0°F<T<5°F)	2.32	3.23	28%
Site 6		Mini-split	2.46	1.47 (0°F<T<5°F)	3.47	3.23	-7%

Table 8. *Consolidated data for multi-family home pilot studies*

PILOT STUDY AND LOCATION	NO. OF SITES	HEAT PUMP MOST CLOSELY REPRESENTING BUILDING MODEL	FIELD MEASURED COP	HEAT PUMP COP EXTRAPOLATED TO NEW YORK CITY	MODELED COP FOR NEW YORK CITY	DIFFERENCE IN COP
University of Albany, NY [32]	1	Geothermal	4.3	4.63	3.60	+29%
DTE Cold Climate HPs, Michigan [33]	44	Ductless	1.56	2.91	3.03	-4%
Efficiency Maine Low Income MF Homes [34]	Multiple	Ductless mini-split	Qualitative data was obtained from these pilots regarding the impact of secondary heating and the design considerations and installation issues.			
Connecticut Energy Efficiency Fund Home Energy Solutions [35]	Multiple	Ductless mini-split				
B.C.M.W. Community Services in Centralia, Illinois [36]	Multiple	Ductless mini- and multi-split				

electric resistance backup. Therefore, the team did not include an explicit discussion of peak demand based on field studies is here; however, the section below describes insights from the field data on heating COPs during the coldest days, which have a strong bearing on heat pumps' peak demand consumption.

4.4 Insights from Heating Efficiency Field Data on the Coldest Days

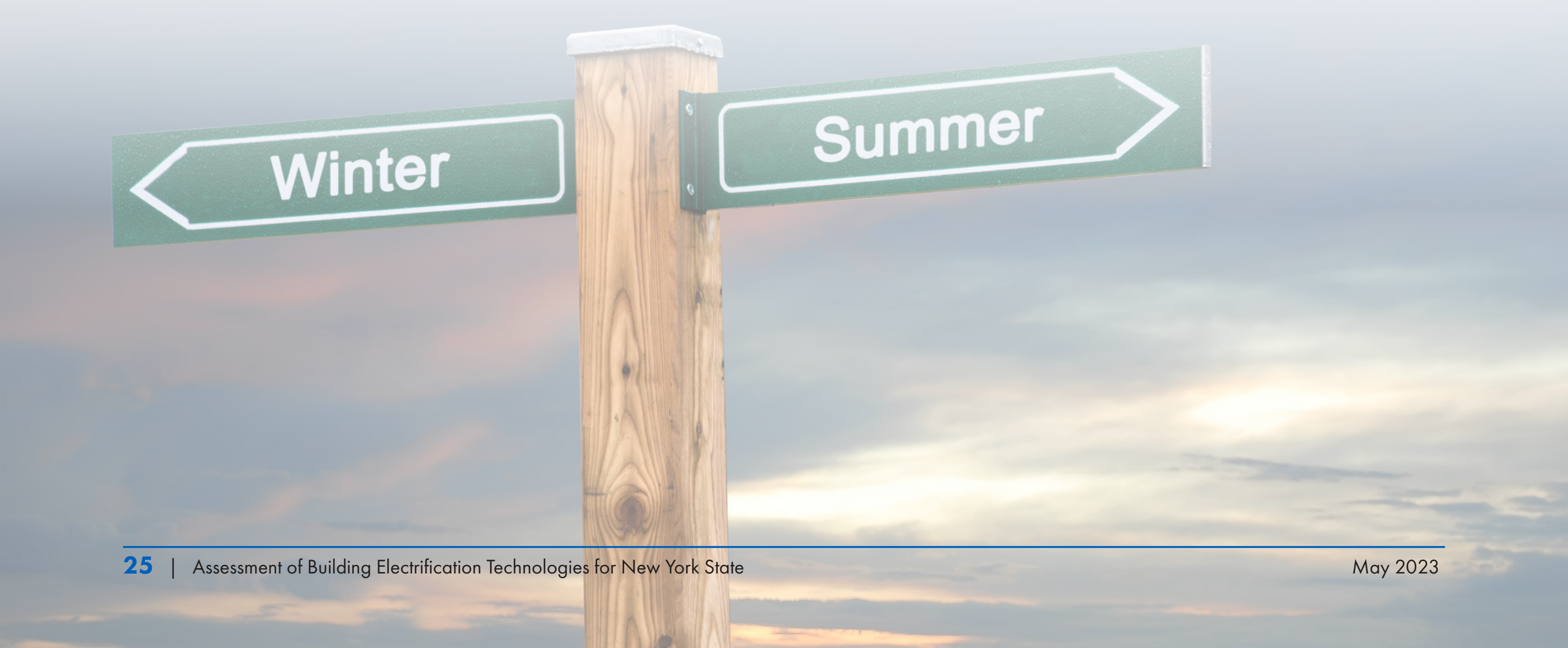
The field studies contain the performance of heat pumps at temperatures below 5°F, both for the ductless and ducted heat pump categories. Table 7 shows that several models of heat pumps were field tested by Center for Energy and Environment's cold-climate air-source heat pump field assessment project that was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources, through the CARD program [29]. In these field studies, three ducted heat pumps tested at three different sites showed COPs of 0.95, 1.6, and 1.7 in the temperature bin of (0, 10)°F for the heat pump cycle only (i.e. without including the efficiency of backup heating). The same three heat pumps in those sites produced a heat pump only COP of 1.4, 1.9, and 1.9 respectively in the temperature bin of (10, 20)°F. All three heat pumps were variable capacity heat pumps and two of the three heat pumps had heating ratings (HSPFs) in the range of today's commercially available cold-climate heat pumps. (All heat pumps had at least 8.5 HSPF heating efficiency or greater.) Note that the overall COP of the system depended on how much additional heat was required from a supplemental heat source to meet the total heating needs, which varied from home to home depending on building characteristics and weather.

The same field study tested ductless heat pumps in two different homes. The specific models of ductless heat pumps chosen for this study had COPs of 1.74 and 1.54 in the temperature bin of (5,10)°F and COPs of 1.76 and 1.47 in the temperature bin of (0,5)°F for the heat pump only mode.

The COP values for cold temperatures in these field studies largely fall within the same range as the COP at winter peak simulated for ductless and cold-climate heat pumps in single-family. Unfortunately, the field studies provide no information on the peak demand for the home that corresponds to these COPs. Also, because the heating energy use and heating COP of the combined system (heat pump and backup) depend on multiple other factors (building characteristics, climate of the location, etc.), the information about the proportion of backup heating used at colder temperatures is less useful.

4.5 Limitations of Field Data Analysis

The data from some of the field studies are incomplete with respect to the quantitative information needed to accurately extrapolate the heating season efficiency. Sources of variability between modeled and field results can result from the nature of backup heat operation in the field. For example, several cold-climate heat pumps in the field used propane/gas backup that operates in either-or-mode (the heat pump shuts off when the backup fossil fuel heating turns on), while the cold-climate heat pumps modeled in this study (described in Section 2) were modeled for electric resistance backup heat, which operates in dual mode (the heat pump and electric resistance operate simultaneously). There could also be potential mismatches in the efficiency of the backup heat, since the modeled results do not account for additional fan energy usage as a result of the backup heat cycling on and off. Additional sources of variability that may have caused a variation between the modeled and measured COP values are variation in field site building geometry compared to modeled values, as well as differences in the way the equipment was sized in the field (e.g., some sites did not have heat pumps sized to heat their basements). The comparison described in Table 7 and COP values stated in Table 8 should therefore be taken as representative or directional values, not as exact values.



SECTION 5: EVALUATION OF NEW YORK STATE ENERGY SYSTEM

5.1 Descriptions of Building Heating Electrification Scenarios

To understand the impact of building electrification on the New York State energy system—including energy consumption and emissions impacts—and to explore strategies for mitigating increases in peak demand, this project examined the potential evolution of consumers' adoption of heat pump technologies under five distinct heating electrification pathways or scenarios. Each scenario is a potential building heating decarbonization pathway that will affect electricity demand throughout the state of New York over the next three decades (to 2050). It is important to note that, individually, these scenarios may not represent practical end states, but future changes will likely include a mix of the technologies and strategies highlighted.

1. **Reference case:** Assumes no restrictions on technology choice except for those already adopted in NYC Local Law 154 of 2021 [38]. Here, future adoption is driven by an economic evaluation of electric and non-electric options (from the customer perspective), with more economically beneficial options gaining market share over time. Macroeconomic growth and energy cost projections draw from EIA's Annual Energy Outlook (AEO) [39], while future electric sector emissions intensities assume 100% zero-emission electricity by 2040 (per the CLCPA [1]).
2. **Widespread adoption of all-electric heat pumps (including supplemental resistance):** A restricted choice set is imposed beginning in 2025 in which customers may only adopt all-electric technology options. Under these restrictions, future adoption is driven by an economic evaluation of available electric options (once again from the customer perspective), which tends to favor the adoption of standard efficiency space and water heating equipment with electric resistance-based auxiliary systems under colder conditions. Based on recent market trends, with policies focusing on cold climate heat pumps, this scenario is unlikely to occur in the future.
3. **Increased adoption of dual fuel heat pumps:** A restricted choice set is imposed beginning in 2025 in which customers may adopt both all-electric and dual-fuel technology options. Once again, an economic evaluation of available options tends to favor the adoption of standard efficiency space and water heating equipment, however, the inclusion of dual-fuel options, which utilize fossil-fueled heating under colder conditions, greatly mitigate impacts to peak. Under this scenario, the number of hours being met by fossil-fueled technologies is greatly reduced than if customers choose fossil-fueled technologies to meet their entire heating needs, thus resulting in lower GHG emissions.
4. **Increased adoption of high-efficiency heat pumps:** A restricted choice set is imposed beginning in 2025 in which customers may only adopt all-electric technology options. Under this scenario, economic considerations are ignored, and higher efficiency space and water heating equipment, such as geothermal heat pumps, cold-climate air source heat pumps, and heat pump water heaters, are adopted. Due to the improved performance under colder conditions, impacts to peak demand are significantly reduced.
5. **Reduced utilization of supplemental resistance:** A restricted choice set is imposed beginning in 2025 in which customers may only adopt all-electric technology options. Under this scenario, economic considerations are ignored, and all space heating equipment is sized to meet a building's heating load, greatly reducing the need for resistance-based auxiliary systems.

The team evaluated each of these scenarios using EPRI's geospatial end-use modeling framework, which enabled them to examine changes in future energy consumption based on differences in market growth, energy efficiency, building stock/floorspace attrition, fuel prices, emission factors, and technology adoption. Assumed heating/cooling performance curves were informed by available field data, as discussed in Section 4. Future changes to equipment efficiencies are based off of 1) AEO projections for increase in SEER and HSPF values over time [40], 2) EPRI's review of historical changes to heat pump efficiency standards of the DOE, and 3) an analysis of observed heating efficiencies in the field. Within each scenario, technology adoption is driven not by external inputs (i.e., predefined adoption curves), but by a discrete choice modeling (logistic) approach in which the relative economic utility of each technology option (both electric and non-electric) is compared—with more economically beneficial options gaining market share over time. A similar approach is taken within EIA's National Energy Modeling System [41], which is used to develop the scenarios published in EIA's AEO.

5.2 Modeling Approach and Data Sources

EPRI's modeling framework for heating electrification scenarios combines various public data sources to estimate final energy consumption at the end-use and equipment-level for different geographies. Data published by the U.S. Census Bureau, EIA, NREL etc. are utilized as data sources to build the model. The data ranges in geographic granularity from national to county-level and are summarized in Table 9.

In addition to the default data sources used to help align baseline consumption estimates with reported consumption data, the team also evaluated supplementary data sources specific to New York State. They reviewed NYSERDA's latest Residential Building Stock Assessment [4], Residential Statewide Baseline Study [5], and Commercial Statewide Baseline Study [6] to define technology saturation data at a more granular sub-state level (e.g., by climate zone or economic region). A summary of the data collected for electrifiable end-uses within the single-family building segment is provided in Figure 15. Similar detail was also obtained for both the multi-family and commercial building segments.

Table 9. Default data sources used within EPRI's Modeling Framework

RELEASE	DATA SOURCE	GRANULARITY
2019	State Energy Data System (SEDS) [42]	State
2021	Annual Energy Outlook (AEO) [39]	National/Census division
2019	American Community Survey (ACS) [43]	County
2019	County Business Patterns (CBP) [44]	County
2015	Residential Energy Consumption Survey (RECS) [7]	Census division
2012	Commercial Buildings Energy Consumption Survey (CBECS) [8]	Census division
1998–2020, TMY	National Solar Radiation Database (NSRDB) [9]	Gridded
v4.11	Gridded Population of the World (GPW) [10]	Gridded

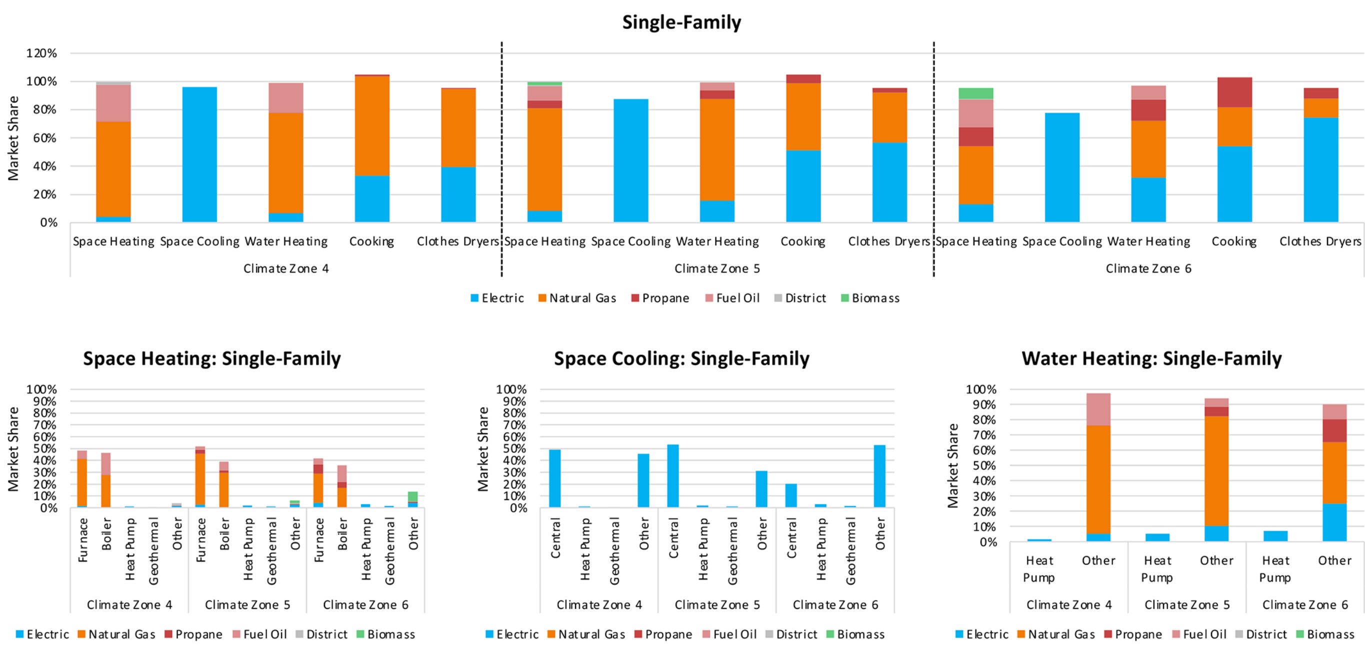


Figure 15. Saturation data collected from NYSERDA's 2019 residential building stock assessment[10]

10 The data is shown only for single-family homes to give readers an idea of the type of data available in NYSERDA's building stock assessment. It is also available for multi-family and commercial buildings but have been excluded to keep this report concise.

For weather dependent end-uses (i.e., space heating, space cooling, and water heating), the study utilizes hourly meteorological data from NREL's National Solar Radiation Database [9] and gridded population data from Columbia University's Socioeconomic Data and Applications Center [10] to capture the impact of variations in climate at a sub-state level. The resulting baseline energy consumption estimates for New York State are shown by sector in Figure 16.

The sub-state granularity of NYSERDA's end-use saturation surveys enabled the further disaggregation of baseline energy consumption estimates by NYISO zone and utility service territory. The results of this analysis are shown in Figure 17 and Figure 18.

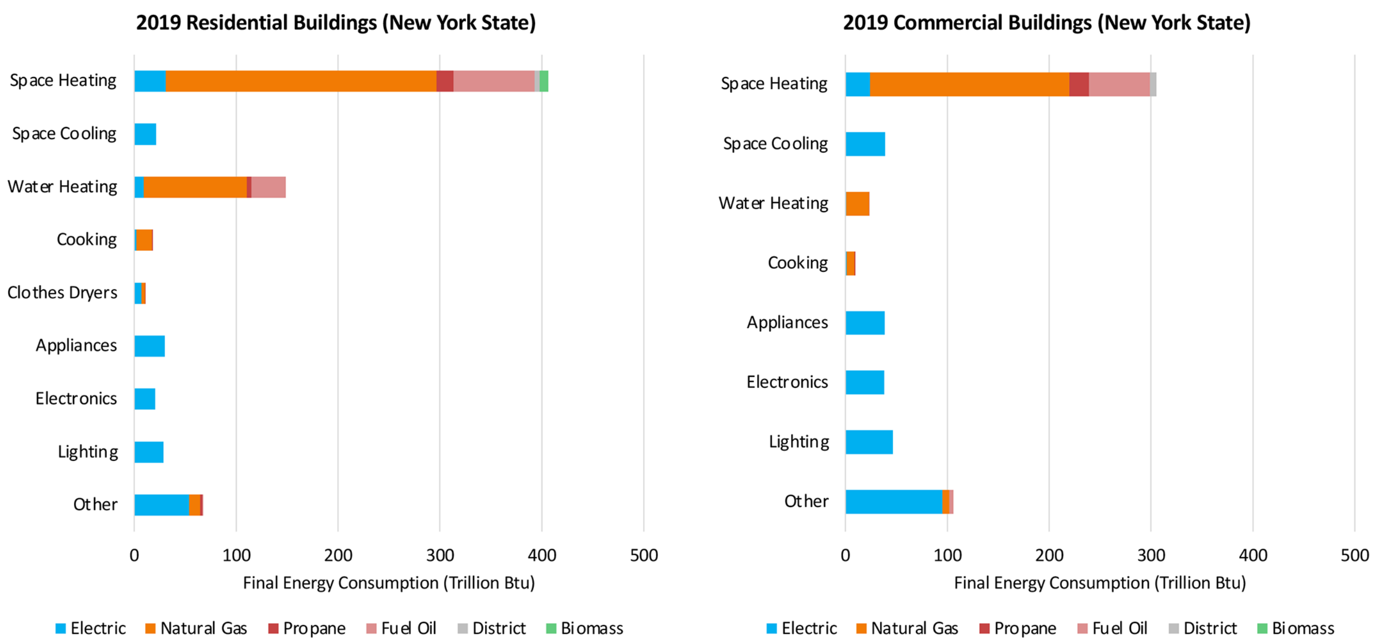


Figure 16. *2019 energy consumption estimates for New York State*

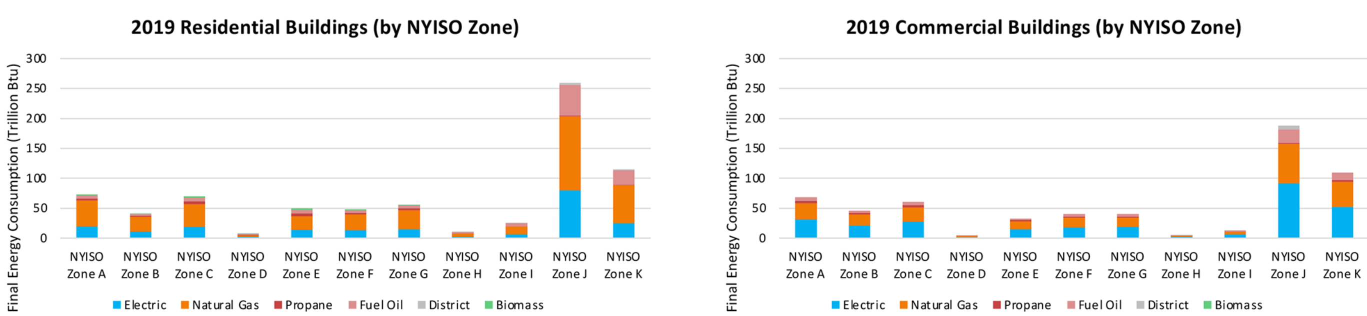


Figure 17. *2019 energy consumption estimates for New York State (by NYISO zone)*

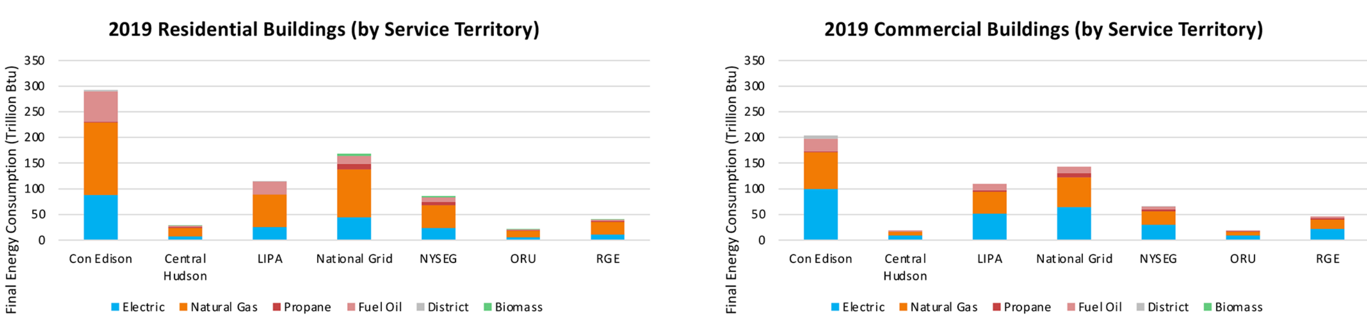


Figure 18. *2019 energy consumption estimates for New York State (by service territory)*

5.3 Evaluation of Heating Electrification Scenarios

The team evaluated future energy consumption based on a number of metrics, the most important of which are market growth, energy efficiency, and electrification. They modeled market growth exogenously based on future building stock and floorspace projections from the AEO, with county-by-county adjustments based on population projections from Cornell University's Program on Applied Demographics [45]. EPRI estimated energy efficiency—which includes building envelope and end-use energy intensity improvements—by sector, building type, building vintage, end-use, equipment type, and fuel type. Finally, electrification was estimated using a discrete choice modeling (logistic) approach in which the relative economic utility of each technology option drives future adoption. EPRI developed inputs to this framework based on market research, pilot/field studies, and subject matter expertise. Figure 19 shows the energy and emissions impacts from the five scenarios considered.

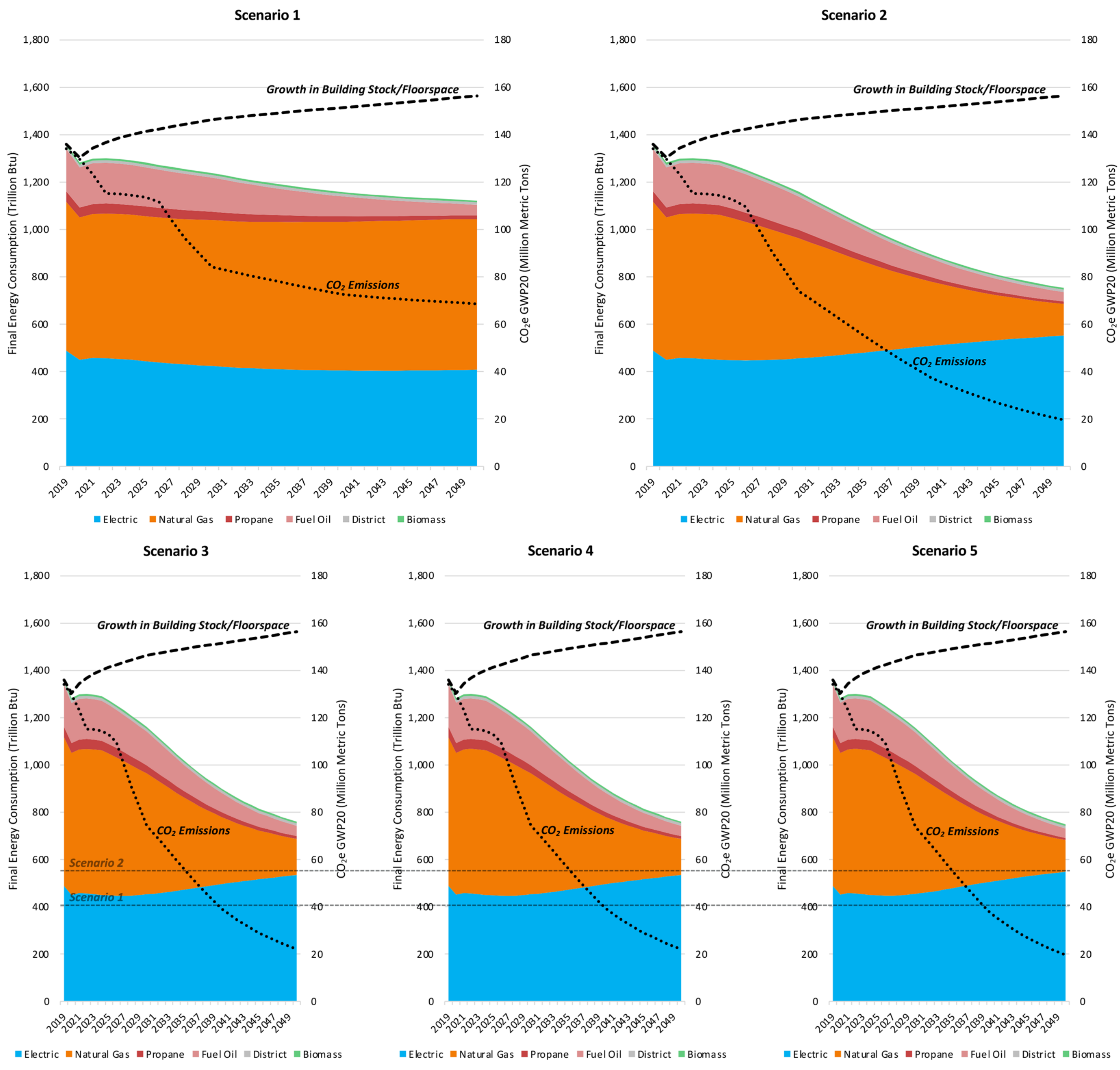


Figure 19. Heating electrification pathways for New York State (energy and emission impacts)

In the reference case, little electrification is expected to occur naturally and growth in electric consumption is outweighed by improvements in efficiency (including building envelope and end-use energy intensity improvements). Larger changes occur in propane and fuel oil usage, which decline through 2050. CO_2e emissions reductions, which were estimated based on average emissions factors and the gross biogenic accounting convention from [46] and [47], are largely driven by efficiency improvements and grid decarbonization; however, under a scenario in which no restrictions are placed on future technology adoption, these reductions are not large enough to meet New York State's goal of 85% carbon reduction (from 1990 levels) by 2050. In contrast, the more aggressive adoption scenarios (2–5) lead to significant changes in the building sector's overall energy mix (i.e., increase in electric and decrease in fossil fuel consumption), while offsetting approximately 48 million metric tons of additional CO_2e compared to the reference case (in line with New York's 85% carbon reduction goal).

To achieve these large reductions in carbon emissions, significant adoption of electric space and water heating equipment occurs in Scenarios 2–5. In these more aggressive scenarios, widespread adoption of heat pump technologies through 2050 increases their overall market share to approximately 70% (Figure 20 and Figure 21). Achieving these accelerated pathways would likely require support from utilities and policy makers. In particular, increases in the share of heat pump equipment in these pathways would need to have dedicated utility and policy support even if equipment economics and fuel costs favor electric over non-electric equipment because of inertial barriers to replace existing fossil fuel equipment, and installation challenges in existing buildings. The latter is particularly true in locations of New York City, where barriers for heat pump installation include a predominantly ductless building stock with hydronic and steam-based equipment and the complexity of deep retrofits in tall buildings. Another challenge particularly stems from the challenges for investment and strategies for low-income housing in the state. Nearly 1.4 million households in New York were considered severely burdened by housing costs that consumed half or more of their income [48]. Developing standardized electrification policies and programs for multi-family buildings is not easy due to the presence of affordable housing units. In these housing units, some potential non-energy benefits of installing heat pumps such as improved indoor air quality from eliminating fossil fuel combustion in an indoor environment, and increased access to cooling in buildings with no prior air conditioning become more significant than in standard housing units. Understanding that the aspect of equity and affordability is not covered in the quantitative analysis for this study, the project team acknowledges that it can play a point in the decision-making process for the consumer.

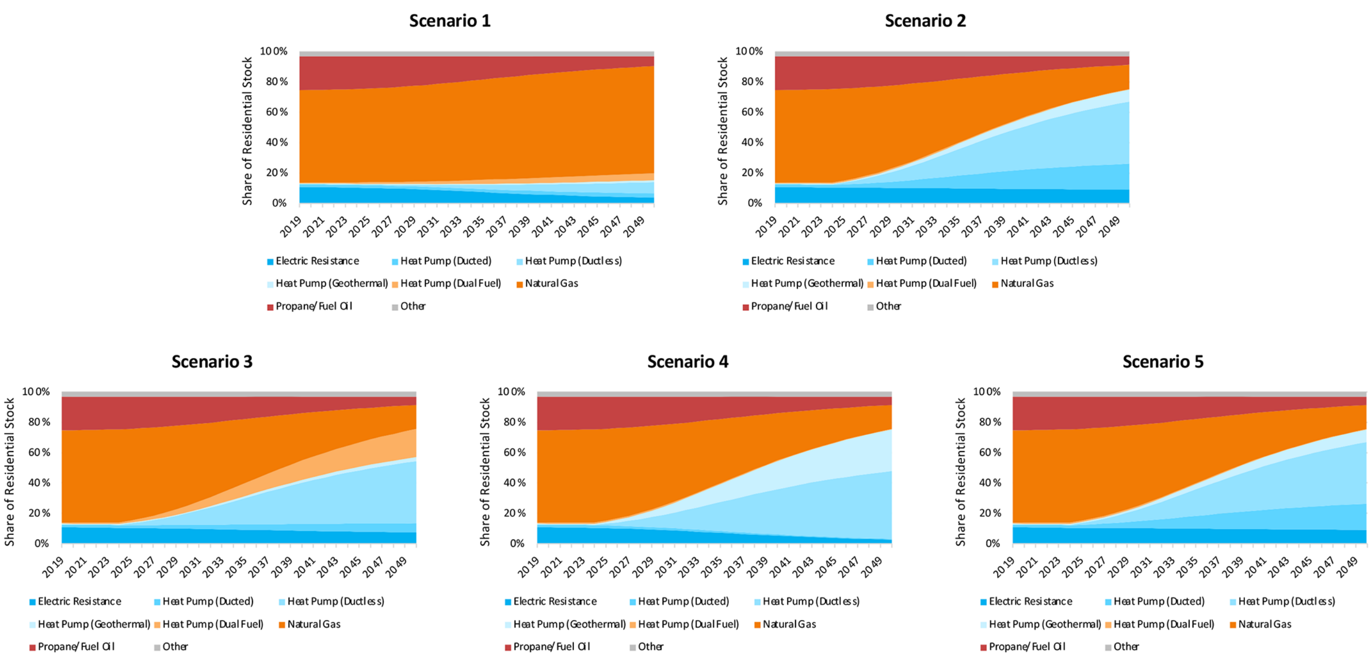


Figure 20. *Space heating equipment market share by scenario (residential buildings)*

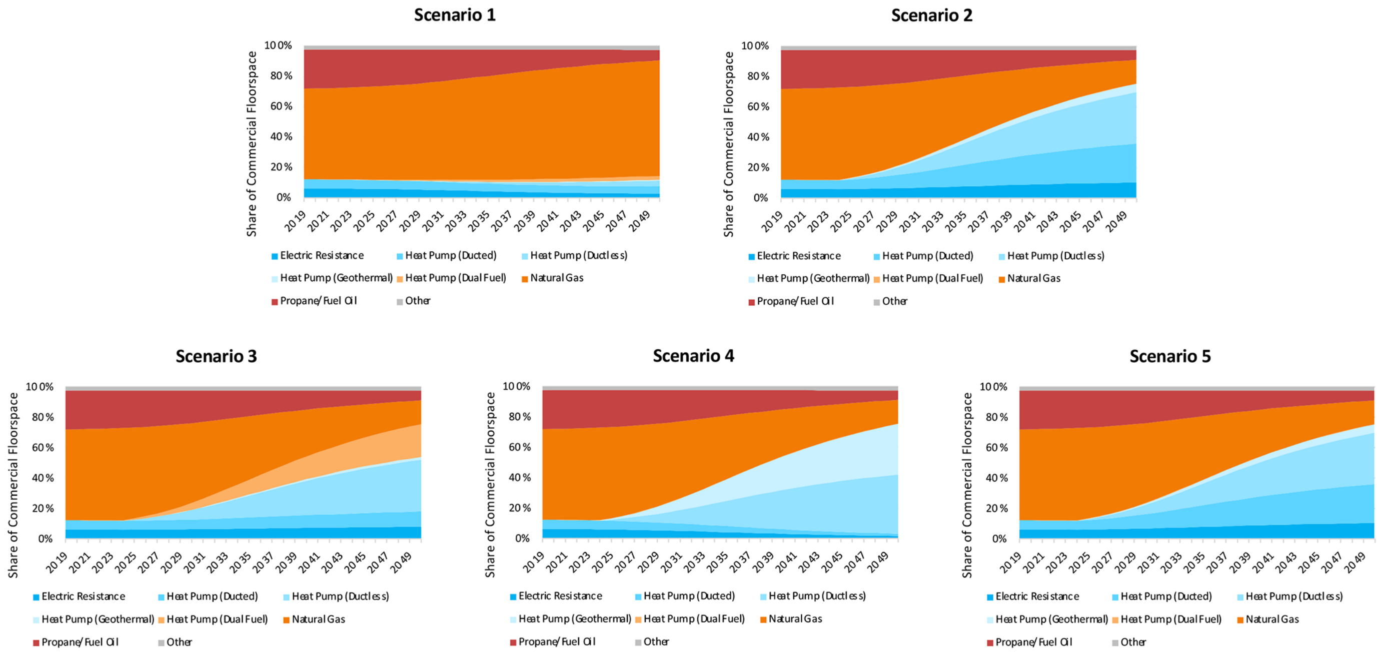
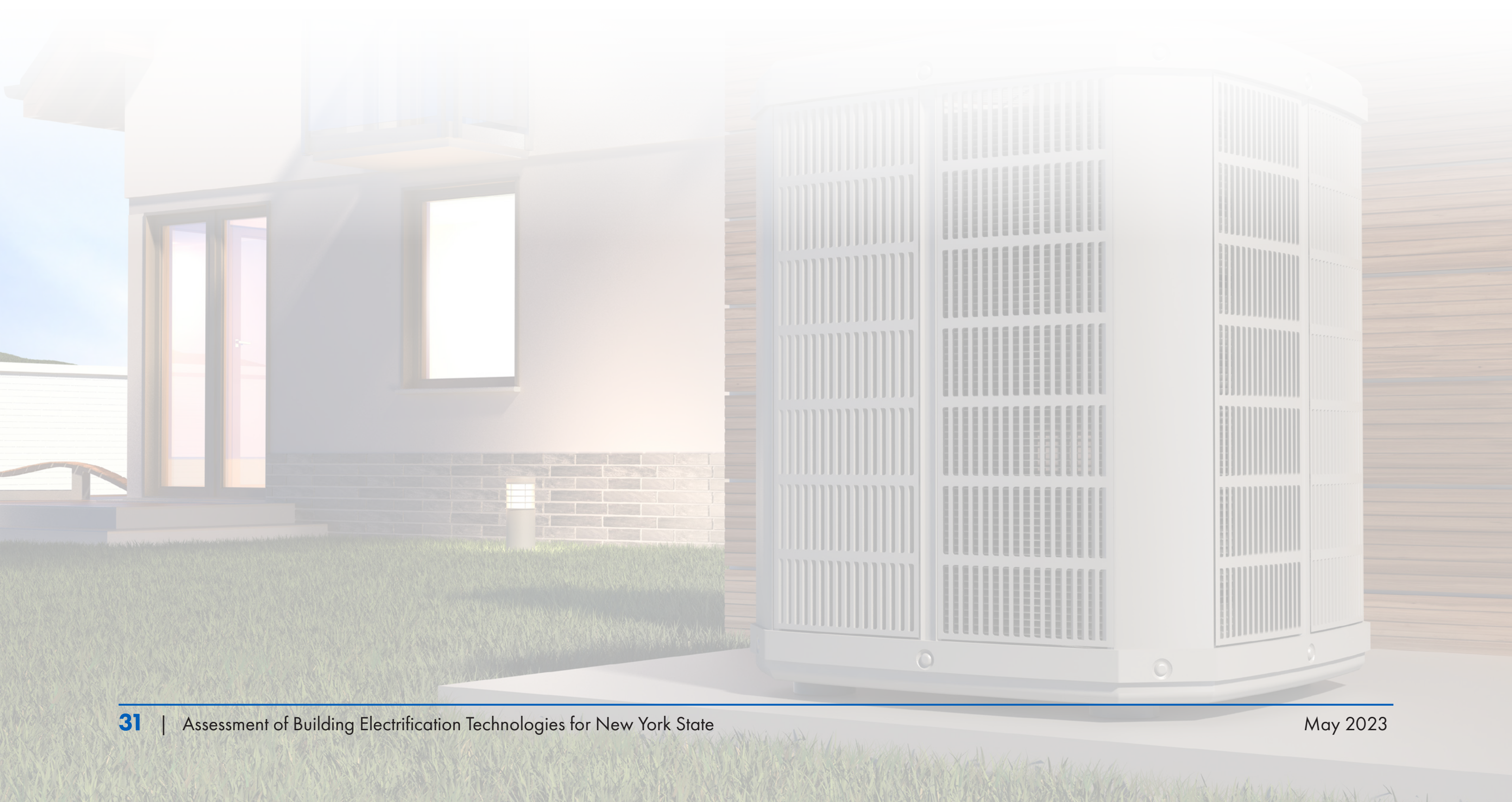


Figure 21. *Space heating equipment market share by scenario (commercial buildings)*



SECTION 6: BUILDING PEAK DEMAND IMPACTS FOR STATE-WIDE ELECTRIFICATION SCENARIOS

6.1 Peak Demand Implications for Various Scenarios

From a state-wide demand perspective, decreases in 2050 summer and winter peak demands compared to the base year are anticipated in the reference case, in which ongoing energy efficiency improvements outweigh future growth in consumption. In contrast Scenario 2, in which adoption is restricted to all-electric technology options, winter peaks increase by 70% due to the need to supplement heat pumps with inefficient resistance backup heating during the coldest hours of the year. From a grid perspective, the widespread utilization of supplemental resistance heating is not desirable and would represent a worst-case-scenario electric peak due to the cost associated with building out the grid to serve this peak. Overall, the results from the first two scenarios represent upper and lower bounds of the analysis, as shown in Figure 22.

Scenarios 3–5 explored opportunities to mitigate peak demand impacts through various end-use technology options. The peak demand implications of these scenarios are shown in Figure 23. In Scenario 3, the installation of dual-fuel options (which utilize fossil fuel-based heating under colder conditions) are not restricted, and dual-fuel technologies capture a modest market share (approximately 20%) through 2050. This is enough to reduce peak demand by approximately 10 GW (20–25%) compared to Scenario 2, while still achieving New York's carbon reduction goals. Similar reductions in peak demand occur in Scenario 4, in which higher efficiency all-electric options, such as geothermal heat pumps, are more widely adopted. While these high efficiency systems can help reduce strain on the electric grid, additional burden falls on the end-use customer due to the higher cost of this equipment. Finally, Scenario 5 explored the possibility of oversizing heating equipment to mitigate the need for inefficient resistance-based auxiliary heating during the coldest hours. Once again, higher costs would be incurred by end-use customers—but compared to Scenario 2, peak demand could be reduced by about 10%.

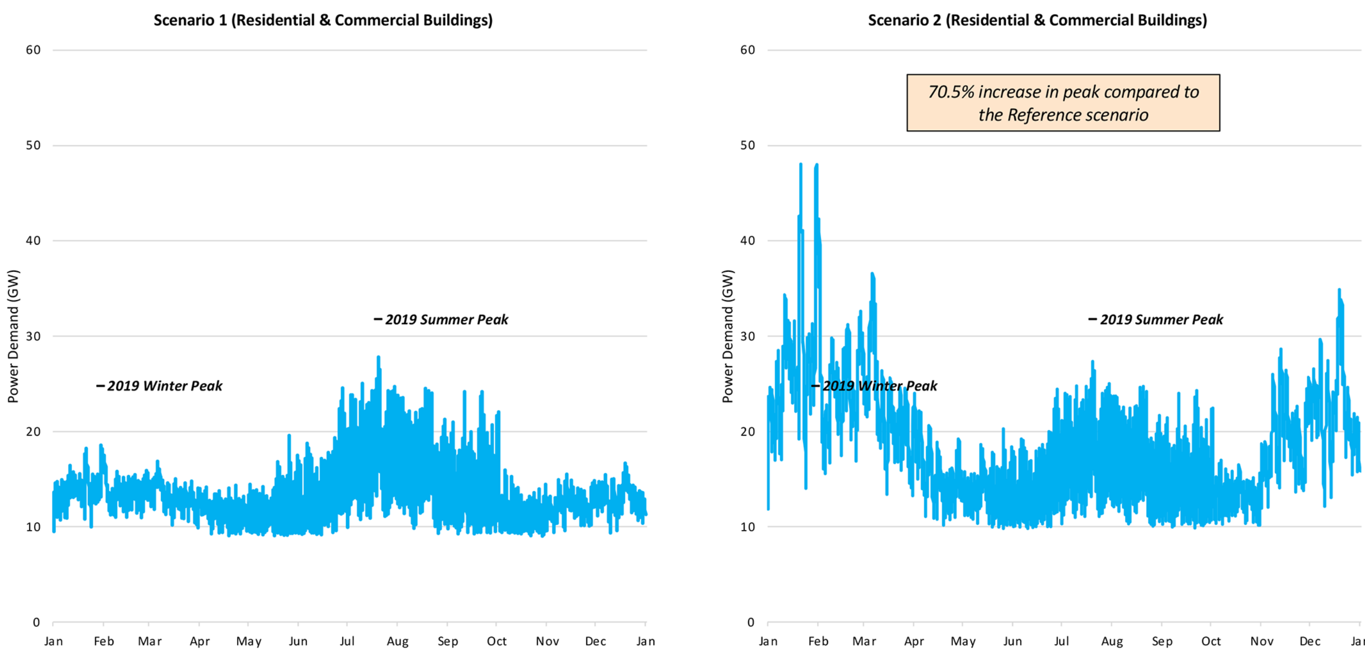


Figure 22. *Heating electrification pathways for New York State (2050 demand impacts, Scenarios 1 and 2)*[11]

11 **Note:** From EPRI's previous analysis (Electrification Scenarios for New York's Energy Future), Transportation and Industrial could account for an additional 15–20 GW of peak demand.

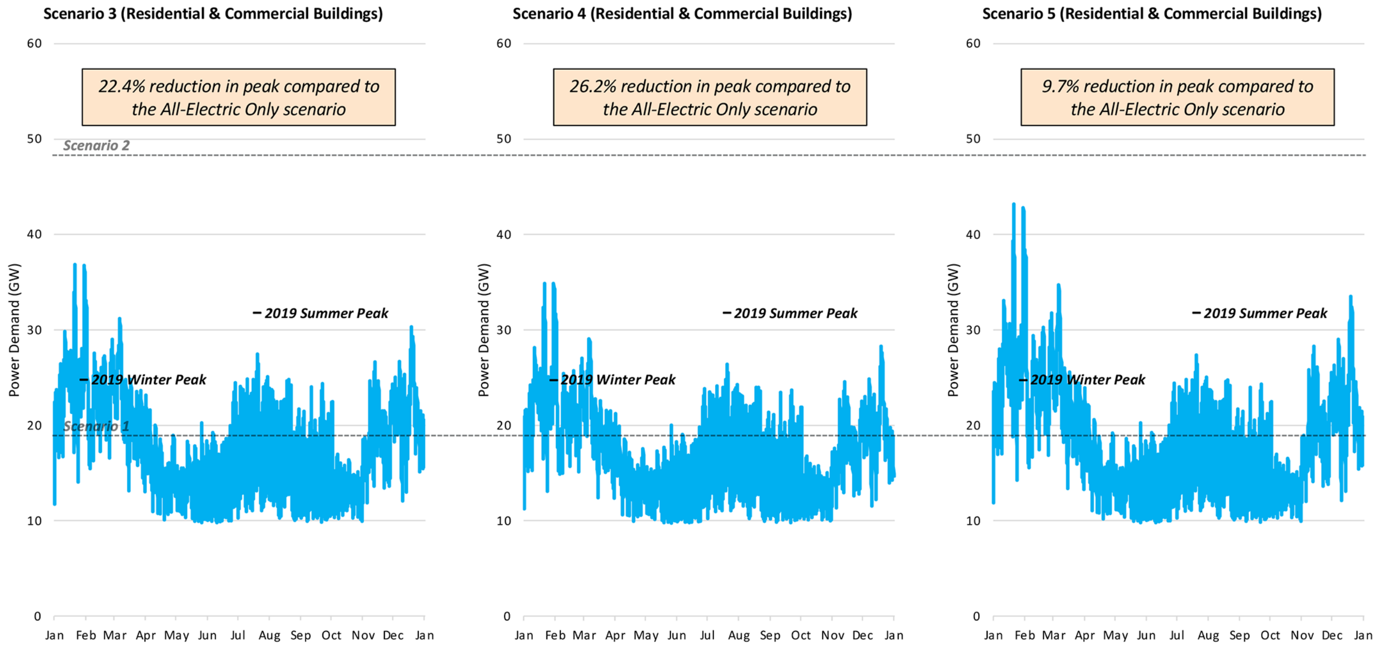


Figure 23. Heating electrification pathways for New York State (2050 demand impacts, Scenarios 3–5) [12]

6.2 Demand Flexibility and Energy Storage

In addition to the strategic adoption of end-use technology options to offset increases in system peak through electrification, demand flexibility and energy storage programs may also be beneficial. While this study only explores these options at a high-level, it is important to highlight the additional challenges associated with seasonality.

For example, current demand flexibility programs across the country tend to focus on reducing summer peaks, which are more predictable with environmental conditions following a diurnal pattern (hotter during the day and cooler in the morning and evening). Opportunities for peak reduction in these cases are typically spread over a ~12-hour window. In contrast, as seen in Figure 24, winter peak events can last significantly longer than similar summer events (e.g., in 2019, the weighted average temperature across the entire state of New York was less than 10°F for 36 consecutive hours). Under these conditions, traditional approaches to space and water heating demand flexibility (e.g., load shifting) will have only a minimal impact on peaks over such an extended timeframe without significantly impacting customer comfort and/or behavior, while more aggressive approaches (i.e., demand reduction) may reduce peaks by 5–10%.

Battery and thermal energy storage technologies may offer flexibility over longer timeframes, but at an additional cost. For example, to reduce the Scenario 2 winter peak to 35 GW, 316 GWh of storage capacity would be required (assuming limited generation capacity is provided by distributed energy resources such as rooftop solar). As a result, future peak mitigation strategies that utilize multiple approaches (i.e., dual-fuel and high efficiency heating systems, equipment sized to reduce the need for resistance-based auxiliary heating, and demand flexibility and energy storage programs), are likely to be the most successful.

12 **Note:** From EPRI's previous analysis (Electrification Scenarios for New York's Energy Future), Transportation and Industrial could account for an additional 15–20 GW of peak demand.

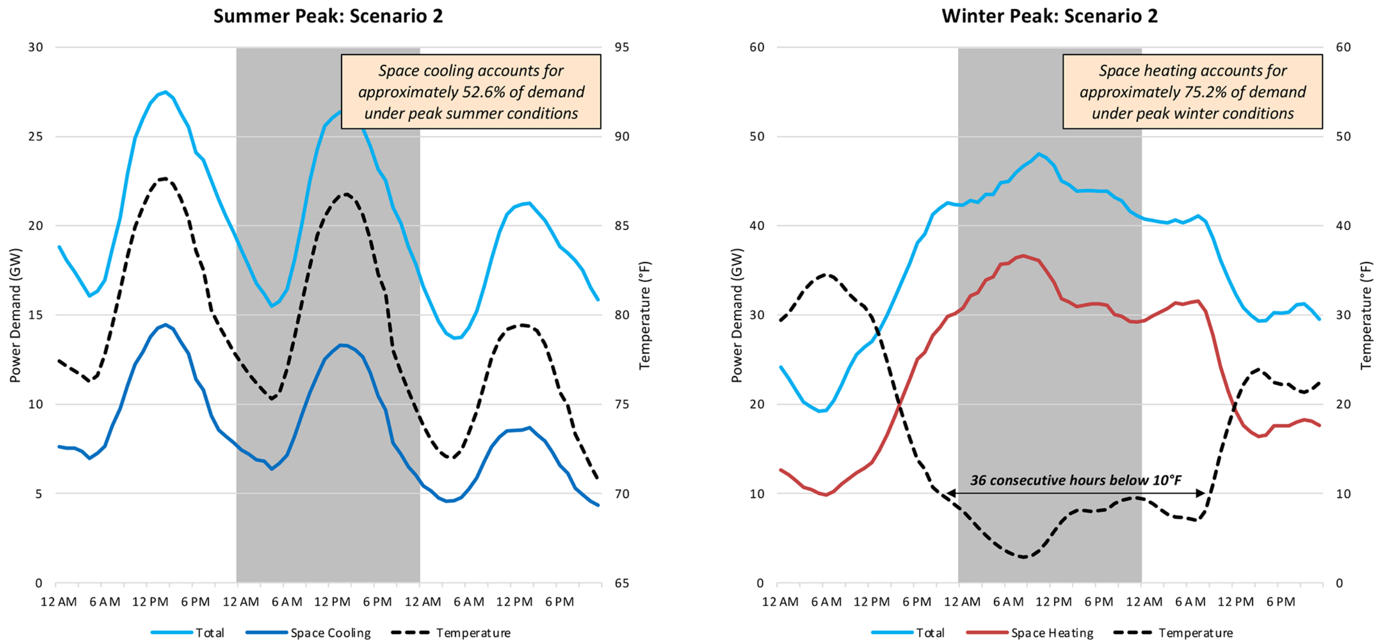


Figure 24. *2050 summer and winter peak events for New York State (Scenario 2)*

6.3 Temperature Sensitivity of Peak Demand

Variations in peak demand due to meteorological conditions will put additional strain on transmission and distribution infrastructure and should be considered when planning future systems upgrades. To better understand these impacts at a high-level, all five electrification pathways were evaluated against a hypothetical weather year in which adjustments were made to peak meteorological conditions to match the average maximum (plus two standard deviations) for summer and the average minimum (minus two standard deviations) for winter. These values fall well outside current heating/cooling design conditions (Note: the results in this section should be interpreted as a sensitivity based on historical data and were not designed to represent future climate trends or extreme weather events which are beyond the scope of this study).

- Historical maximum temperature for New York State (population weighted): 89.8°F
- 2-sigma maximum temperature for New York State (population weighted): 96.2°F
- Historical minimum temperature for New York State (population weighted): 4.7°F
- 2-sigma minimum temperature for New York State (population weighted): -6.9°F

Under this modified meteorological scenario, new summer and winter peak weather conditions lead to changes in demand, with summer peaks estimated to increase by approximately 1.2 to 1.8 GW (4.5– 6.4%) and winter peaks estimated to increase by approximately 3.5–16.3 GW (18.7–34.5%). This is shown in Figure 25. Overall, it is important to note that based on the inherent operating characteristics and relative performance of heat pump systems, winter peaks are expected to be more sensitive to severe weather conditions than corresponding summer peaks. From the perspective of building electrification, this analysis reinforces the need for reevaluating the electric system design standard to ensure system reliability in severe winter weather conditions.

6.4 Impact of Various Pathways on Peak Demand

The impact of peak demand due to electrification can also be viewed using a waterfall chart, as shown in Figure 26. In this chart, the expected peak demand values in 2050 for residential and commercial buildings under widespread adoption of electric heating technologies is shown. Note that these results represent the entire state but excludes electrification impacts of transportation are industrial end-uses, which are expected to add further to the peak demand values.

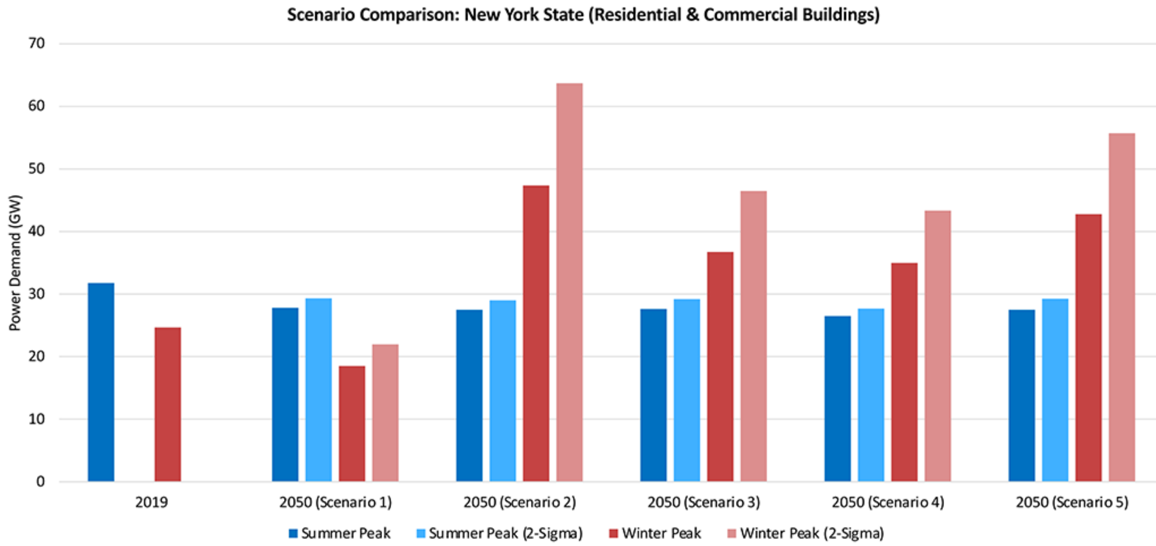


Figure 25. *2050 summer and winter peaks for New York State (2-sigma temperature variation)* [13]

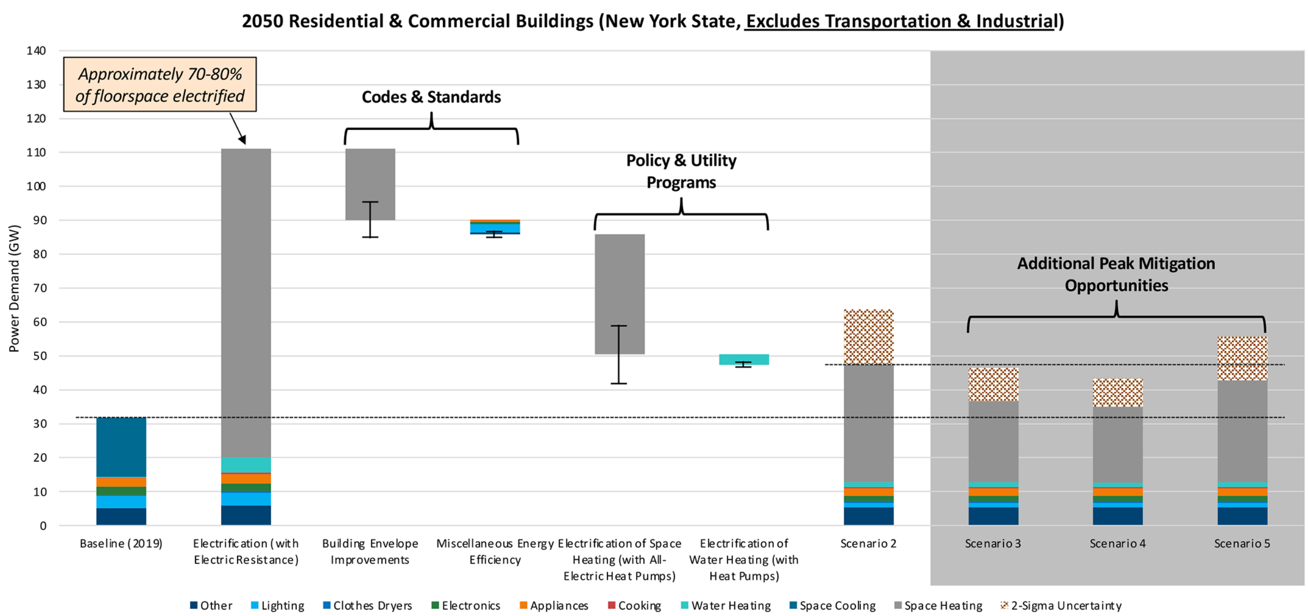


Figure 26. *2050 residential and commercial buildings peak demand waterfall chart* [14, 15]

13 **Note:** From EPRI's previous analysis (Electrification Scenarios for New York's Energy Future), Transportation and Industrial could account for an additional 15–20 GW of peak demand.

14 **Note:** From EPRI's previous analysis (Electrification Scenarios for New York's Energy Future), Transportation and Industrial could account for an additional 15–20 GW of peak demand.

15 Within codes & standards, envelope improvements are based on a historical review of prior building codes and projections from the AEO for future codes while miscellaneous energy efficiency improvements are estimated by EPRI (Note: a detailed review of existing energy efficiency programs was not conducted as part of this study).

Under these aggressive scenarios, (where approximately 70–80% of floorspace is electrified) peak demand could increase by a factor of 3 if the existing stock of equipment is electrified using inefficient electric resistance as the heat source. Space heating is the biggest contributor to this peak demand, with more than 90GW contributed by space heating. Increases in peak demand can be mitigated to a certain extent by implementing additional codes and standards and through policy and utility programs (a detailed review of existing energy efficiency programs was not conducted as part of this study with error bars added to represent uncertainty). These are inclusive of building envelope improvements, use of heat pump technology for space heating and water heating, and miscellaneous improvements energy efficiency improvements. Based on a literature review of energy efficiency potential for building envelope improvements from the AEO, we derived an envelope improvement of about 20% through 2050 compared to current levels. Additional improvements were assumed on the policy side, causing the end-use technologies for HVAC systems to become more efficient over time. Implementation of these measures can reduce the peak demand by nearly half, to about 50 GW.

The result of implementing the mitigation measures described above leads to the peak demand value modeled in Scenario 2. Compared to 2019, this still represents a nearly 16 GW increase in peak demand which today's electric infrastructure is insufficient to meet. Transportation and industrial end-uses, which were not considered in this study, are also expected to have a non-trivial contribution to the demand (in EPRI's 2019 study "Electrification Scenarios for New York's Energy Future" [2], it was found that Transportation and Industrial end-uses could account for an additional 15–20 GW of peak demand). Scenarios 3 through 5 provide additional opportunities to consider for peak mitigation, however these scenarios have their own implementation challenges in terms of addressing customer perceptions, overcoming high upfront equipment costs, and increasing the awareness of vendors, installers and contractors.

Regardless of the scenario considered, increased electrification in New York State will require utilities to substantially upgrade distribution infrastructure throughout the state. This will have rippling effects upstream in the electric grid, needing upsizing of wires, feeders, reclosers, and substations. As a result, future transmission infrastructure will also require improvements to ensure that the transmission wires are sized to handle the larger distribution system. Finally, unique challenges related to electrification will be seen across the state. While this analysis considered regional differences regarding initial technology saturation, future population growth, and climate conditions, additional market barriers exist throughout the state. For example, due to the size and age of buildings in New York City, these buildings may be more difficult electrify, requiring higher costs and more time to plan for changes. Similarly, the potential for ground source heat pumps (i.e., Scenario 4) has challenges such as space requirements for drilling and installing the ground loop that make them unsuitable in many cases, including in many areas of New York City and when retrofitting existing buildings. As a result, different levels of policy support may be required to address barriers that are unique to each region within New York State.

SECTION 7: SUMMARY OF KEY FINDINGS

EPRI's "Assessment of Building Electrification Technologies for New York State" study examines the potential of efficient building heating electrification solutions in the state. A key driver for this study is the underlying fact that state utilities are deeply examining electrification as a building decarbonization solution to meet the state's CLCPA goals, as well as individual city laws adopted in New York City. This study has been successful in explicitly modeling the feasibility of substantial CO_2 reductions under various building electrification scenarios. The following points summarize the study's key findings:

- The study found a large potential for reducing carbon emissions within the New York State energy system through the electrification of building heating end-uses, particularly through efficient space heating technologies.
- The study successfully characterized the impact of efficient building envelopes on building heating electrification. This provides the stakeholders with valuable information, such as the impact of building envelope efficiency on equipment sizing, energy use, electrical upgrade infrastructure needs, and costs, thus preparing them for sustainable building design practices and deployment of high-performance HVAC systems.
- To adopt electric heating solutions in buildings, the infrastructure needed to support them needs to be present. Electric infrastructure planning is based on the cumulative electric demand from all end-uses, of which building electrification is a key component. Therefore, this study analyzes building electrification—particularly the electrification of space heating through the use of heat pumps—from the perspective of energy performance, economics, carbon emission reduction potential, and peak demand impact. The utilities can incorporate the various results of building electrification into their overall frameworks for analysis of electrification assessment. Of course, the overall framework for decision making will also include electricity demand implications from the electrification of transportation and industrial end-uses.
- This study builds on a prior EPRI study, "Electrification Scenarios for New York's Energy Future," which stated that New York's winter climate and building stock call for advanced technologies and targeted approaches to building heating electrification when compared to other areas of the United States. Accordingly, this study provides a detailed examination of the impacts of emerging heat pump solutions such as cold-climate heat pumps and geothermal heat pumps, which offer the potential for mitigating peak demand that could result from widespread adoption of electric resistance heating. Widespread adoption of these technologies may be limited, however, due to higher upfront costs.
- While advances in heat pump technology and the increased awareness of the state's carbon policies help to shift the market from fossil fuels toward electrified end-uses, electrification of building heating will ultimately depend on individual customer decisions. Retrofitting large commercial and residential buildings is particularly economically challenging and disruptive to customers. Therefore, to accelerate technology adoption and advance building heating electrification, factors such as market readiness, technology maturity, vendor-to-customer education, and cost will be crucial.

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