Space Heating with Heat Pumps: The Need for Alternative Rate Designs in Massachusetts

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Applied Economics Clinic

Prepared for: Green Energy Consumers Alliance (GECA)

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About the Applied Economics Clinic

Based in Boston, Massachusetts, the Applied Economics Clinic (AEC, www.aeclinic.org) is a mission-based non-profit consulting group that offers expert services in the areas of energy, environment, consumer protection, and equity from seasoned professionals while providing on-the-job training to the next generation of technical experts.

AEC's non-profit status allows us to provide lower-cost services than most consultancies, and when we receive foundation grants, AEC also offers services on a pro bono basis to environmental justice-focused community-based organizations. AEC's clients are primarily public interest organizations—non-profits, government agencies, and green business associations—who work on issues related to AEC's areas of expertise. Our work products include expert testimony, analysis, modeling, policy briefs, and reports, on topics including energy and emissions forecasting, economic assessment of proposed infrastructure plans, and research on cutting-edge, flexible energy system resources.

AEC works proactively to support and promote diversity in our areas of work by providing applied, on-the-job learning experiences to graduate students—and occasionally highly qualified undergraduates—in related fields such as economics, environmental engineering, and political science. Over the years, AEC has hosted research assistants from Boston University, Brandeis University, Clark University, Tufts University, University of Massachusetts-Amherst, University of Massachusetts-Boston, University of Southern Maine, and University of Tennessee. AEC is committed to a just workplace that is diverse, pays a living wage, and is responsive to the needs of our staff.

Founded in 2017 by Director and Senior Economist Elizabeth A. Stanton, PhD, AEC's talented researchers and analysts provide a unique service-minded consulting experience. Dr. Stanton has had more than two decades of professional experience as a political and environmental economist leading numerous studies on environmental regulation, alternatives to fossil fuel infrastructure, and local and upstream emissions analysis. AEC professional staff includes experts in electric, multi-sector and economic systems modeling, climate and emissions analysis, green technologies, and translating technical information for a general audience. AEC's staff are committed to addressing climate change and environmental injustice in all its forms through diligent, transparent, and comprehensible research and analysis.

I. Introduction

Heating electrification is a decarbonization strategy that uses efficient electric heat pumps to generate heat in homes and businesses instead of fossil fuels like gas, oil, and propane. Buildings are a significant contributor to greenhouse gas emissions, driven by the on-site use of fossil fuels for heating, cooking, and other end-uses. Electrifying heating systems with heat pumps at scale will enable states and other jurisdictions to achieve their ambitious climate goals, especially as efforts to decarbonize the electric grid advance. Using current-day rate structures on customer utility bills, however, the most prevalent and cheapest to install “air-source” heat pumps are not always the most cost-effective heating option relative to fossil-fuel heating technologies, especially in cold weather regions like New England.

Through its 2008 Global Warming Solutions Act (GWSA),[1] Massachusetts established a statewide greenhouse gas emission reduction target of achieving at least 80 percent of 1990 levels by 2050.[2] In April 2020, Massachusetts’ Governor Baker issued a letter establishing a net zero[3] greenhouse gas emissions target by 2050.[4] In December 2020, the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) released the *2050 Decarbonization Roadmap*, outlining the possible pathways to meeting the Commonwealth’s ambitious climate targets.[5] Across all net zero-compliant pathways, electrification of building heating technology, or the replacement of gas and oil furnaces and boilers with heat pumps, is an essential and cost-effective strategy for decarbonization.[6]

To assess the role of gas utilities and the future of existing gas infrastructure in Massachusetts as the buildings sector transitions away from gas heating, the Massachusetts Department of Public Utilities (DPU) launched Docket No. 20-80, *Investigation by the Department of Public Utilities on its own Motion into the role of gas local distribution companies as the Commonwealth achieves its target 2050 climate goals*.[7] The objective of Docket No. 20-80 was to identify ways in which local gas distribution companies (i.e., gas utilities) can effectively decarbonize their gas supply. Through this proceeding, DPU has reviewed several different decarbonization futures for gas utilities; the goal has not been to recommend a preferred pathway or technology, but rather to establish a regulatory framework that safeguards ratepayers, promotes equity, and enables the Commonwealth to achieve its climate targets. In December 2023, DPU issued an order in Docket No. 20-80 that focuses on a “beyond gas” future by requiring gas utilities to examine non-gas pipeline alternatives (e.g.,

[1] Massachusetts General Laws Chapter 298 (GWSA), (2008). *An Act Establishing the Global Warming Solutions Act*. Available at: https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter298

[2] (1) Massachusetts General Laws Chapter 298 (GWSA), Section 3(a) (2008). *An Act Establishing the Global Warming Solutions Act*. Available at: https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter298; (2) Mass.gov. N.d. “Global Warming Solutions Act Background.” Available at: https://www.mass.gov/info-details/global-warming-solutions-act-background

[3] “Net Zero” is defined as: “A level of statewide greenhouse gas emissions that is equal in quantity to the amount of carbon dioxide or its equivalent that is removed from the atmosphere and stored annually by, or attributable to, the Commonwealth; provided, however, that in no event shall the level of emissions be greater than a level that is 85 percent below the 1990 level.” See: Massachusetts Executive Office of Energy and Environmental Affairs (EEA) and The Cadmus Group. December 2020. “Massachusetts 2050 Decarbonization Roadmap.” Available at: https://www.mass.gov/doc/ma2050-decarbonization-roadmap/download. p.7

[4] Commonwealth of Massachusetts. April 22, 2020. “Press Release: Baker-Polito Administration Issues Letter Establishing Net Zero Emissions Target.” Available at: https://www.mass.gov/news/baker-polito-administrationissues-letter-establishing-net-zero-emissions-target.

[5] Massachusetts Executive Office of Energy and Environmental Affairs (EEA). 2020. *Massachusetts 2050 Decarbonization Roadmap*. Available at: https://www.mass.gov/info-details/ma-decarbonization-roadmap

[6] Ibid. p.45.

[7] Massachusetts Department of Public Utilities (DPU) Docket No. 20-80. *Investigation by the Department of Public Utilities on its own Motion into the role of gas local distribution companies as the Commonwealth achieves its target 2050 climate goals.* Available at: https://eeaonline.eea.state.ma.us/DPU/Fileroom/dockets/bynumber/20-80

electrification, networked geothermal systems, etc.) prior to making further investments in gas pipeline infrastructure that may be stranded assets in the future. DPU's order also requires a regulatory strategy based on six design recommendations and directs gas utilities to submit individual Climate Compliance Plans every five years beginning in 2025.[8]

In March 2021, GWSA was amended by the *Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy*[9] to establish a net zero greenhouse gas emissions target by 2050 with an interim target of achieving at least 50 percent reduction of 1990 levels by 2030.[10] The 2021 Act also required the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) to establish sector-based statewide greenhouse gas emission sublimits.[11] Released by the EEA in 2022, the *Massachusetts Clean Energy and Climate Plan for 2025 and 2030* (2025/30 CECP) outlines the strategies, policies, and actions that will enable the Commonwealth to meet climate and clean energy goals.[12] The 2025/30 CECP also set 2030 emission sublimits for each economic sector, including a 49 percent reduction in 1990 levels for heating and cooling activities in the residential, commercial, and industrial sectors.[13] The 2025/30 CECP notes that energy efficiency upgrades and heating electrification efforts are among the Commonwealth's primary strategies for achieving emission reductions from heating and cooling activities in its buildings sectors:

> *Heating in buildings by oil and gas represented 30% of statewide GHG emissions in 2020. The Commonwealth's primary strategies to reduce emissions from buildings are to improve the energy efficiency of buildings and convert the heating systems for homes and businesses to electric heat pumps.*[14]

As Massachusetts makes the changes needed to achieve net-zero emissions by 2050, households and businesses that use gas and other fossil fuels for heating will need to transition to other energy sources with lower greenhouse gas emissions. The *2050 Decarbonization Roadmap* and 2025/30 CECP reports both highlight the need to decarbonize the buildings sector using efficient electric heating technologies like heat pumps powered by renewable energy.

In September 2023, Massachusetts Senator Barrett proposed a bill—titled *An Act Reducing the Financial Penalty Imposed On Customers Who Shift to Heat Pumps, Electric Appliances, and Electric Vehicles*—to petition for legislation to reduce the financial penalty and increase accessibility of electrification for customers of all income ranges.[15] If passed, the bill would create an income-based electric rate schedule in which a set of fixed

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[8] DPU Docket No. 20-80. December 2023. "Order on Regulatory Principles and Framework (DPU 20-80-B)." *Investigation by the Department of Public Utilities on its own Motion into the role of gas local distribution companies as the Commonwealth achieves its target 2050 climate goals.* Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/18297602

[9] Massachusetts General Laws Chapter 8, (2021). *An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy.* Available at: https://malegislature.gov/Laws/SessionLaws/Acts/2021/Chapter8

[10] (1) ClimateXchange. N.d. "Massachusetts." Available at: https://climate-xchange.org/dashboard/map/massachusetts/; (2) Mass.gov. N.d. "Mitigating Greenhouse Gas Emissions." Available at: https://www.mass.gov/mitigating-greenhouse-gas-emissions; (3) Massachusetts Executive Office of Energy and Environmental Affairs (EEA). 2022. *Massachusetts Clean Energy and Climate Plan for 2025 and 2030.* Available at: https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download, p. xi

[11] Massachusetts General Laws Chapter 8, (2021). *An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy.* Available at: https://malegislature.gov/Laws/SessionLaws/Acts/2021/Chapter8

[12] Massachusetts Executive Office of Energy and Environmental Affairs. 2022. *Massachusetts Clean Energy and Climate Plan for 2025 and 2030*. Available at: https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download

[13] The 2025/30 CECP also sets an emission sublimit for the natural gas distribution and service sector as an 82 percent reduction in 1990 greenhouse gas emission levels. Source: Ibid. p.23.

[14] Ibid. p. xiii.

[15] The Commonwealth of Massachusetts. Senate Docket No. 2748. September 2023. *An Act reducing the financial penalty imposed on customers*

charges (i.e., any charge that does not change substantially with the amount of electricity consumed) vary by income, so that low-income customers would pay less relative to higher-income customers.[16] Energy burden—the percentage of household income spent on energy bills—is typically higher for low-income households; While the Massachusetts state average is about 3 percent, the average for low-income households is about 10 percent.[17] Addressing energy burden for low-to moderate-income customers can alleviate financial hurdles that can be a barrier to families wanting to take advantage of electrification opportunities, such as heat pump adoption.[18]

This Applied Economics Clinic (AEC) white paper, prepared on behalf of the Green Energy Consumers Alliance (GECA), presents a preliminary assessment of costs to customers heating with air-source heat pumps, and discusses the need for alternative electric rate designs to make heating electrification cost effective in Massachusetts. The white paper begins in Section II by providing an overview of different heat pump technologies, their benefits, and obstacles for deployment. Section III evaluates the direct and indirect impacts on customer electric bills due to heating electrification. Section IV discusses different types of rate structures and their uses and applicability for heating electrification. Section V concludes the white paper with key takeaways and recommendations to support heating electrification in Massachusetts using alternative rate designs. The Methodology Appendix documents the methodology and data sources used to conduct the calculations on the impacts of heating electrification presented in this white paper.

II. Space Heating with Heat Pumps

Roughly three-quarters of Massachusetts households heat their homes with fossil fuels (see Figure 1 below). In contrast, only about 18 percent of Massachusetts households have electric heating systems, and most of those systems are old-fashioned electric resistance heating not modern, efficient heat pumps.[19] According to the U.S. Energy Information Administration's 2020 Residential Energy Consumption Survey (RECS), only 2 percent (or 100,000 households) of New England's 5.9 million households heat their homes using heat pumps.[20] This white paper focuses on the comparison of heating with electric heat pumps versus gas-fired heating technologies. Gas is the most prominent fuel source for heating in Massachusetts, representing half of all home heating fuel use. In addition, gas heating systems represent the biggest economic challenge to electrification due to their low operation prices compared to other fossil fuels like oil and propane.

who shift to heat pumps, electric appliances, and electric vehicles. Available at: https://malegislature.gov/Bills/193/SD2748.pdf

[16] Ibid, p.1

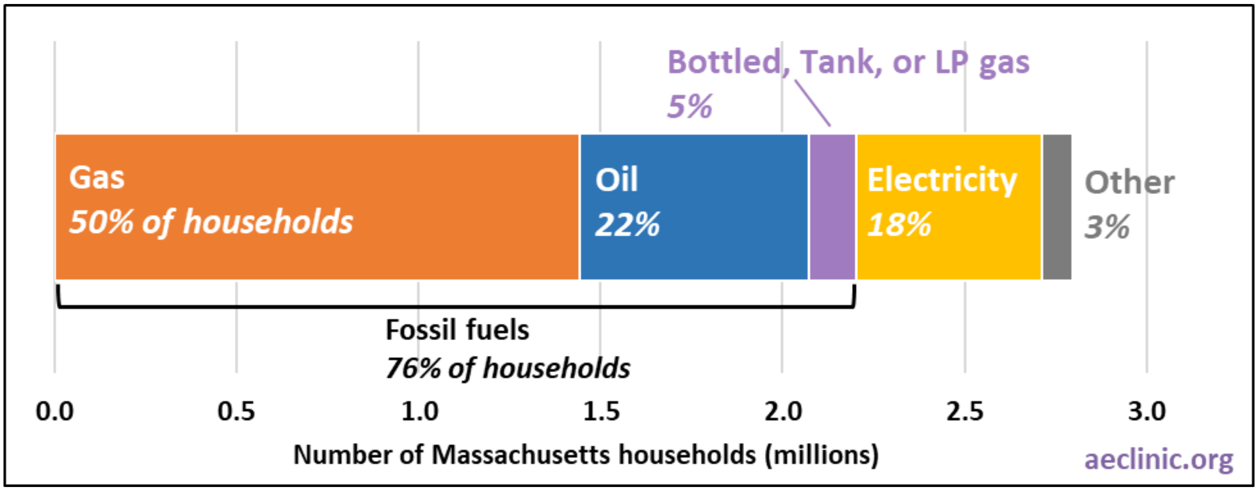
[17] Metropolitan Area Planning Council (MAPC). 2022. "Reducing Energy Burden: Resources for Low-Income Residents." Available at: https://www.mapc.org/planning101/reducing-energy-burden-resources-for-low-income-residents/#:~:text=Energy%20burden%20is%20defined%20as,as%20high%20as%2031%20percent

[18] Ibid.

[19] U.S. Census Bureau. 2022. "House Heating Fuel" [Table]. American Community Survey 1-Year Estimates. Available at: https://data.census.gov/table/ACSDT1Y2022.B25040?q=B25040:+House+Heating+Fuel&g=040XX00US25

[20] U.S. Energy Information Administration (EIA). 2020. "Table HC6.7 Space heating in homes in the Northeast and Midwest regions" [Table]. Available at: https://www.eia.gov/consumption/residential/data/2020/hc/pdf/HC%206.7.pdf

Figure 1. Home heating fuels used in 2022 by Massachusetts households



Data source: U.S. Census Bureau. 2022. ACS 1-Year Detailed Estimates [Table: B25040]. Available at: *https://data.census.gov/table/ACSDT1Y2022.B25040?q=B25040:+House+Heating+Fuel&g=040XX00US25*

ISO-New England's *2023 Heating Electrification Forecast* predicts that about 3.5 percent of Massachusetts households will have heat pumps installed in their homes by 2035.[21] According to the *2050 Decarbonization Roadmap*'s Buildings Sector Report, Massachusetts would need to deploy electric heat pumps to nearly 100,000 homes each year to achieve the emission reductions required in the residential buildings sector.[22] This pace of deployment translates to nearly 1.5 million heat pump installations in Massachusetts homes (or 50 percent of the current housing stock) by 2035;[23] this scale of heat pump adoption is more than 14 times larger than ISO-New England's forecast.

Benefits of space heating with electric heat pumps

Electric heat pumps are a type of heating and cooling system that operates by transferring heat either into or out of a building. During the colder months, heat pumps use electricity to move heat into buildings from outside and vice versa during the warmer months. There are three main types of heat pump systems:[24]

- **Air-source heat pumps (ASHP):** ASHPs heat and cool a building by using electricity to transfer heat either inside or outside the building. Temperature control comes from tweaking the difference between the outside and inside air temperature—not from the electricity itself. On average, ASHPs generate three units of heating energy for every one unit of electric energy used to run them (300 percent efficiency). However, the heating efficiency for ASHPs varies depending on the difference between indoor and outdoor air temperatures (i.e., lower efficiency for colder outdoor air temperatures and higher efficiency for warmer outdoor air temperatures).[25]

[21] ISO-New England. 2023. *Final 2023 Heating Electrification Forecast* [PowerPoint]. Available at: https://www.iso-ne.com/static-assets/documents/2023/04/heatfx2023_final.pdf. p. 22.

Massachusetts Executive Office of Energy and Environmental Affairs (EEA). 2020. *Buildings Sector Report*. Prepared by The Cadmus Group, Arup, VEIC, Energy Futures Group, and Evolved Energy Research. Available at: https://www.mass.gov/doc/buildings-sector-technical-report/download, p.7.

[23] U.S. Census Bureau. "National, State, and County Housing Unit Totals: 2020-2022." Available at: https://www.census.gov/data/tables/time-series/demo/popest/2020s-total-housing-units.html

[24] U.S. Department of Energy. n.d. "Heat Pump Systems." Available at: https://www.energy.gov/energysaver/heat-pump-systems

[25] Personal communication with Mike Simons, Abode Energy Management in February 2023.

- **Ground-source heat pump (GSHP):** GSHPs rely on the consistent underground temperature maintained up to 400 feet belowground or in a body of water.[26] Like other heat pumps, GSHPs operate by transferring heat either into or out of a building. GSHPs generate four and a half units of heating energy for every unit of electric energy used to run them (450 percent efficiency) and offer consistent levels of efficiency regardless of outdoor air temperatures.
- **Networked geothermal systems:** Interconnecting GSHPs in multiple buildings throughout a neighborhood using an underground shared loop of ambient-temperature water can further improve the efficiency of this technology. A networked geothermal system allows for excess energy not needed by one building to be moved to networked buildings that do need that energy.[27] Networked geothermal systems generate six to eight units of heating energy for every unit of electric energy used to run them (600 to 800 percent efficiency).

Compared to conventional heating systems powered by fossil fuels, electric heat pumps have the potential to provide households with several benefits (or avoided costs), including but not limited to:

1. **Improved public health and safety.** Heat pumps are safer than gas-fired heating systems that pose the risk for fire and explosion in and around homes, schools, and businesses.[28] In September 2018, failures in utility supervision led to a series of gas explosions and fires in Massachusetts' Merrimack Valley, which resulted in one death, twenty-two hospitalizations, and a three-month period in which it was unsafe to restore electric and gas service in the area.[29] Space heating with heat pumps also improves public health by decreasing indoor air pollution from conventional gas- or oil-fired heating systems.[30]
2. **Emission reductions.** Heat pumps also provide an opportunity for substantial emission reductions when paired with a decarbonized grid that is powered by renewable energy. Through its Clean Energy Standard (CES), Massachusetts aims for at least 80 percent of electric sales to be procured from clean energy resources[31] by 2050.[32]

[26] U.S. Department of Energy. N.d. "Geothermal Heat Pumps." Available at: https://www.energy.gov/energysaver/geothermal-heat-pumps

[27] Home Energy Efficiency Team (HEET). n.d. "Networked Geothermal." Available at: https://heet.org/geo/

[28] (1) Campbell, R. 2020. *Structure Fires in Schools*. National Fire Protection Association. Available at: https://www.nfpa.org/News-and-Research/Data-research-and-tools/Building-and-Life-Safety/Structure-fires-in-schools; (2) Glick D., Plautz, J. 2018. "The rising risks of the West's latest gas boom." High Country News. Available at: https://www.hcn.org/issues/50.18/energy-industry-how-site-workers-and-firefighters-responding-to-a-2017-natural-gas-explosion-in-windsor-colorado-narrowly-avoided-disaster

[29] (1) U.S. Attorney's Office, District of Massachusetts. June 23, 2020. "Columbia Gas Sentenced in Connection with September 2018 Gas Explosions in Merrimack Valley" [Press Release]. Available at: https://www.justice.gov/usao-ma/pr/columbia-gas-sentenced-connection-september-2018-gas-explosions-merrimack-valley; (2) NTSB. 2019. *Overpressurization of Natural Gas Distribution System, Explosions, and Fires in Merrimack Valley, MA*. Pipeline Accident Report NTSB/PAR-19/02. Available at: https://www.ntsb.gov/investigations/

[30] 1) Gas Leaks Allies. n.d. "Gas Leaks Kill Trees." Available at: https://www.wellesleyma.gov/DocumentCenter/View/9596/Gas-Leaks-Kill-Trees-PDF#:~:text=Gas%20leaks%20have%20killed%20street,cost%20taxpayers%20millions%20of%20dollars; (2) Schollaert, C., Ackley, R. C., DeSantis, A., Polka, E., and Scammell, M. K. 2020. "Natural gas leaks and tree death: A first-look case-control study of urban trees in Chelsea, MA USA." *Environmental Pollution, 263(A)*. Available at: https://doi.org/10.1016/j.envpol.2020.114464 ; (3) Storrow, B. May 5, 2020. "Methane Leaks Erase Some of the Climate Benefits of Natural Gas." Scientific American. Available at: https://www.scientificamerican.com/article/methane-leaks-erase-some-of-the-climate-benefits-of-natural-gas/

[31] "Clean energy resources" are defined to include any Class I renewable technology (e.g., solar, wind, small hydropower, landfill methane and anaerobic digester gas, marine or hydrokinetic, geothermal, and eligible biomass fuel) as well as other energy technologies that meet the emissions-based performance standard defined by the CES. Source: Massachusetts Department of Environmental Protection (DEP). December 2022. "310 CMR 7.75: Clean Energy Standard (CES) Frequently Asked Questions (FAQ) Version 2.2." Available at: https://www.mass.gov/doc/frequently-asked-questions-massdep-clean-energy-standard/download

[32] Massachusetts Department of Environmental Protection (DEP) and Executive Office of Energy and Environmental Affairs (EEA). *Clean Energy Standard (310 CMR 7.75).* Available at: https://www.mass.gov/guides/clean-energy-standard-310-cmr-775

3. **Energy cost savings.** Unlike other heating technologies, heat pumps have the dual purpose of providing both space heating and cooling services. In warmer months, households that utilize heat pumps to cool their homes realize energy savings—and thus lower energy bills—compared to other options such as window air conditioning units that are less efficient and require more energy to run. In cooler months, heat pumps provide households with a cost-effective heating option.

Barriers to electric heat pump adoption

Although heat pump technologies are more efficient than conventional heating systems, physical, economic, and informational barriers all contribute to the slow uptake of residential heat pump installations in Massachusetts and beyond (see Table 1 below). Even as heat pumps become increasingly competitive with gas heating, obstacles like high upfront costs and limited access to credit continue to place heat pumps just out of reach for many of the households, especially low- to moderate-income households, that would benefit the most from a transition away from gas.

Table 1. Potential barriers for heat pump installations

Barriers	Descriptions
Physical	Obstacles that hinder the retrofit of existing heating systems, such as: • substandard electrical systems, • incompatible infrastructure, and • limited workforce capacity.
Economic	Financial restraints that impede widespread adoption of heat pumps, particularly for low- and moderate-income households, such as: • high upfront costs, and • limited access to credit.
Informational	The perceptions of available heating options can limit heat pump installs due to: • inadequate information/misinformation, • status quo bias, and • slow stock turnover.

Source: Reproduced from: Castigliego, J.R., Alisalad, S., Stasio, T., and Stanton, E.A. 2021. Inflection Point: When Heating with Gas Cost More. Applied Economics Clinic White Paper, AEC-2021-01-WP-01. Available at: https://aeclinic.org/publicationpages/2021/01/13/inflection-point-when-heating-with-gas-costs-more. [Table 2].

Outside of these barriers, the operation of ASHPs (but not networked geothermal and GSHPs) are strongly influenced by climate conditions, with colder outdoor temperatures decreasing efficiency and increasing operation costs. Additional barriers related to equipment specifications, electricity rates, and rate structures apply to all types of heat pumps, making a close comparison of operation costs across different types of heating equipment essential to forming realistic building decarbonization policies.[33] An "operating cost gap" is a measure that can be used to determine whether switching from one heating system to another would be a cost-effective choice for a given household. The "cost gap" is the difference between current and expected future operating costs and can be used to compare different heating systems. A household looking to electrify its heating system by switching from a gas-fired furnace to ASHPs will include this operating cost gap in its decision-making.

[33] Sergici, S., A. Ramakrishnan, G. Kavlak, A. Bigelow, and M. Diehl. January 2023. "Heat Pump-Friendly Cost-Based Rate Designs." A White Paper from the Retail Pricing Task Force. Reston, VA: Energy Systems Integration Group (ESIG). Available at: https://www.esig.energy/aligningretail-pricing-with-grid-needs.

In the case of home heating electrification, an operating cost gap between a gas-fired furnace and an ASHP could impose a financial penalty. Expected (or forecast) operating cost gaps could act as a deterrent to the widespread heat pump adoption that is necessary to achieve Massachusetts' emission reductions targets. On the flipside, a negative operating cost gap (where heat pumps can be run less expensively than gas furnaces) could also present a cost savings for households and act as an incentive to heat pump adoption. Savings from a negative operating cost cap can help offset the high upfront costs associated with heating electrification.

III. Impacts of Heating Electrification

Although heating electrification can help achieve building decarbonization goals, it can have negative impacts on customer electric bills if not carefully addressed in rate design. These customer bill impacts can be a direct result of current electric rates and rate structures, or an indirect result of impacts on electric system costs due to changes to demand and peak load. The 2025/30 CECP highlights the need for responsible energy infrastructure planning to account for expected impacts on the electricity grid due to the deployment of electric heat pumps:

> *Responsible energy infrastructure planning is thus a key priority for building decarbonization. For the electricity grid, deployment of electric heat pumps will significantly increase both total annual demand for electricity and the demand required during the coldest hours of the year. Although it is unlikely that heat pump adoption would drive peak growth until sometime after 2030, investment in electric infrastructure should be planned today.*[34]

Impacts on customer energy bills

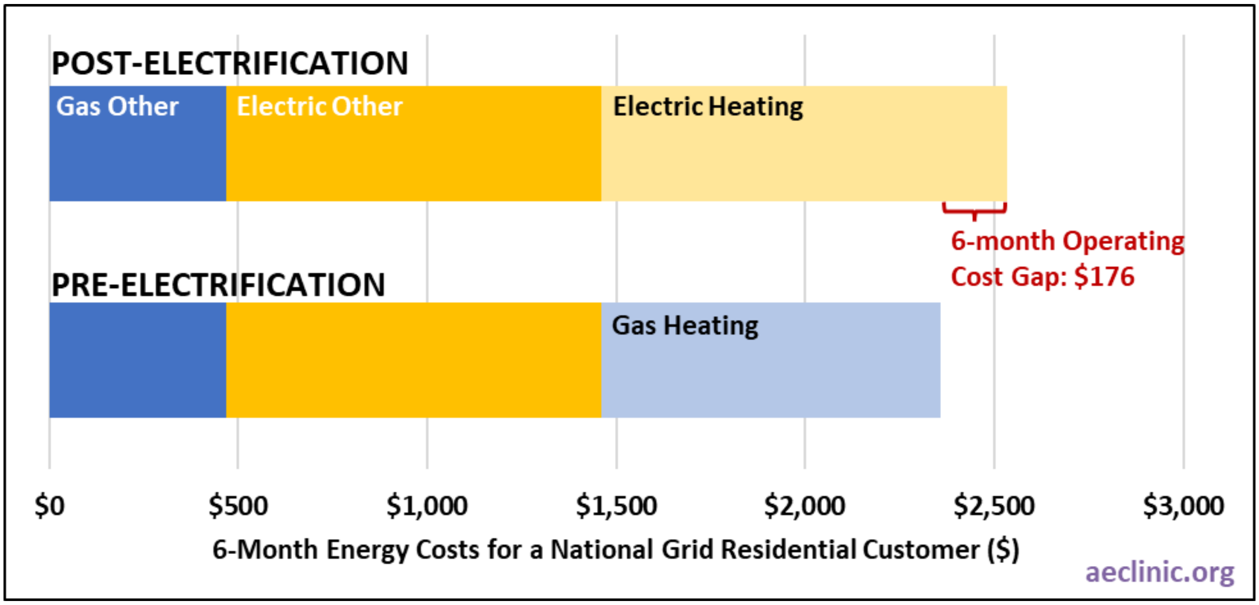
AEC analyzed the impact of heating electrification on customer energy bills by evaluating total energy costs—using current Massachusetts utility rates and rate structures—for an average residential customer during the six-month heating season, which includes both gas and electric usage for heating and base (non-heating) end-uses. AEC's analysis focuses on the comparison of electric and gas-fired heating technologies; gas currently represents the largest share of home heating fuels in Massachusetts and is more competitive with electric heat pumps than oil and propane on a $ per MMBtu basis.

In an average-sized Massachusetts home, heating with ASHPs results in an operating cost gap, compared to gas heating, between $166 and $605 (depending on the electric distribution company) over the 6-month heating season between November and April (see FiguresFigure 2,Figure 3, andFigure 4 below for results associated with each of Massachusetts' largest electric distribution companies); this means that electric ASHP heating costs roughly $28 to $101 more per month than gas heating.

For this analysis, AEC gas costs were based on average rates across all of Massachusetts' gas distribution companies, while electric costs were evaluated for each individual electric distribution company. National Grid and Eversource both have similar volumetric electric rates ($ per kWh) leading to operating cost gaps that only differ by $10 across the six-month heating season (or $1.67 per month). In contrast, Unitil's operating cost gap is 3.4 to 3.6 times higher than the other two electric distribution companies (or a difference of $429 to $439 across the six-month heating season), which is due to its volumetric electric rates being nearly 30 to 50 percent higher.

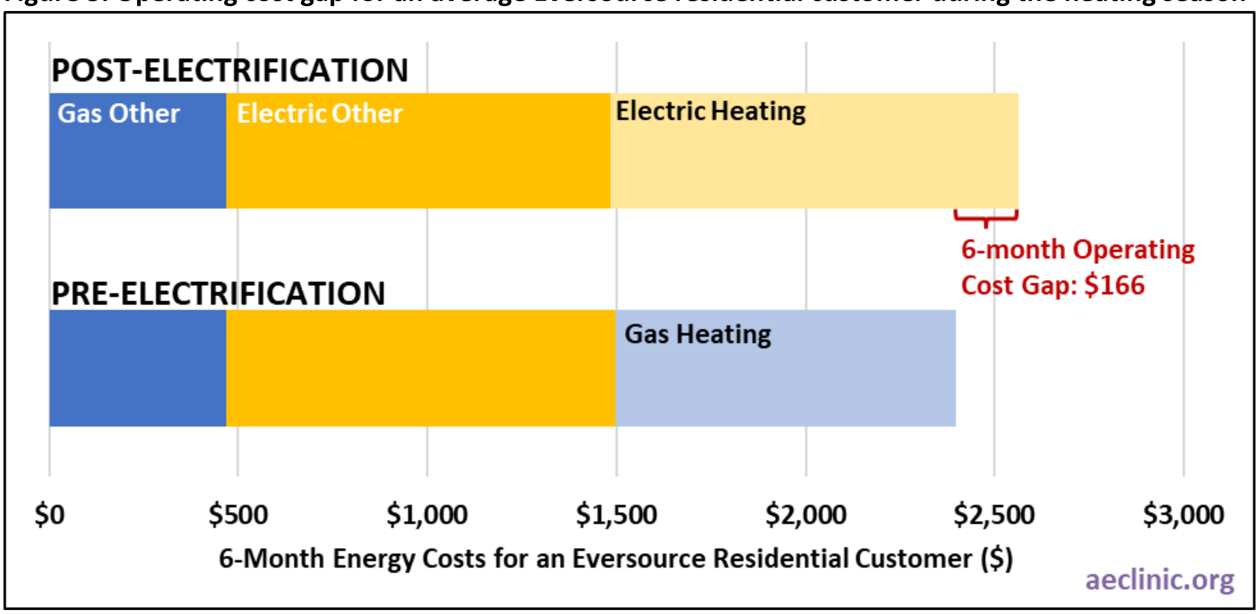
[34] Massachusetts Executive Office of Energy and Environmental Affairs (EEA). 2022. *Massachusetts Clean Energy and Climate Plan for 2025 and 2030*. Available at: https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download p.60

Figure 2. Operating cost gap for an average National Grid residential customer during the heating season



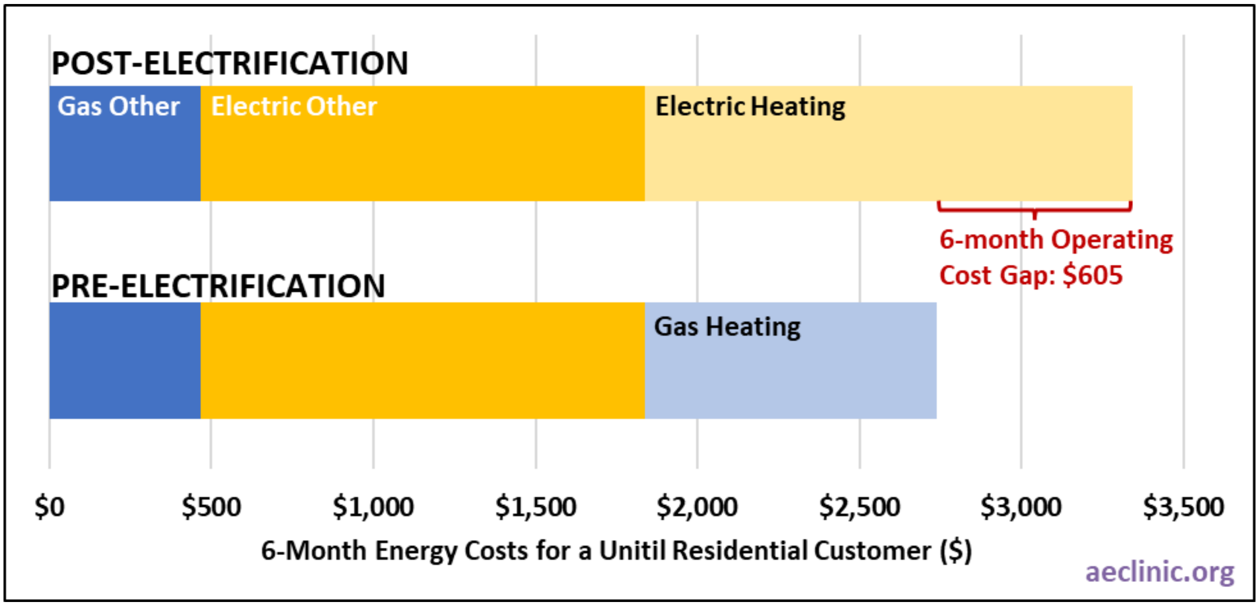
Data source: AEC calculations, see Methodology Appendix for description of calculations and data sources.

Figure 3. Operating cost gap for an average Eversource residential customer during the heating season



Data source: AEC calculations, see Methodology Appendix for description of calculations and data sources.

Figure 4. Operating cost gap for an average Unitil residential customer during the heating season



Data source: AEC calculations, see Methodology Appendix for description of calculations and data sources.

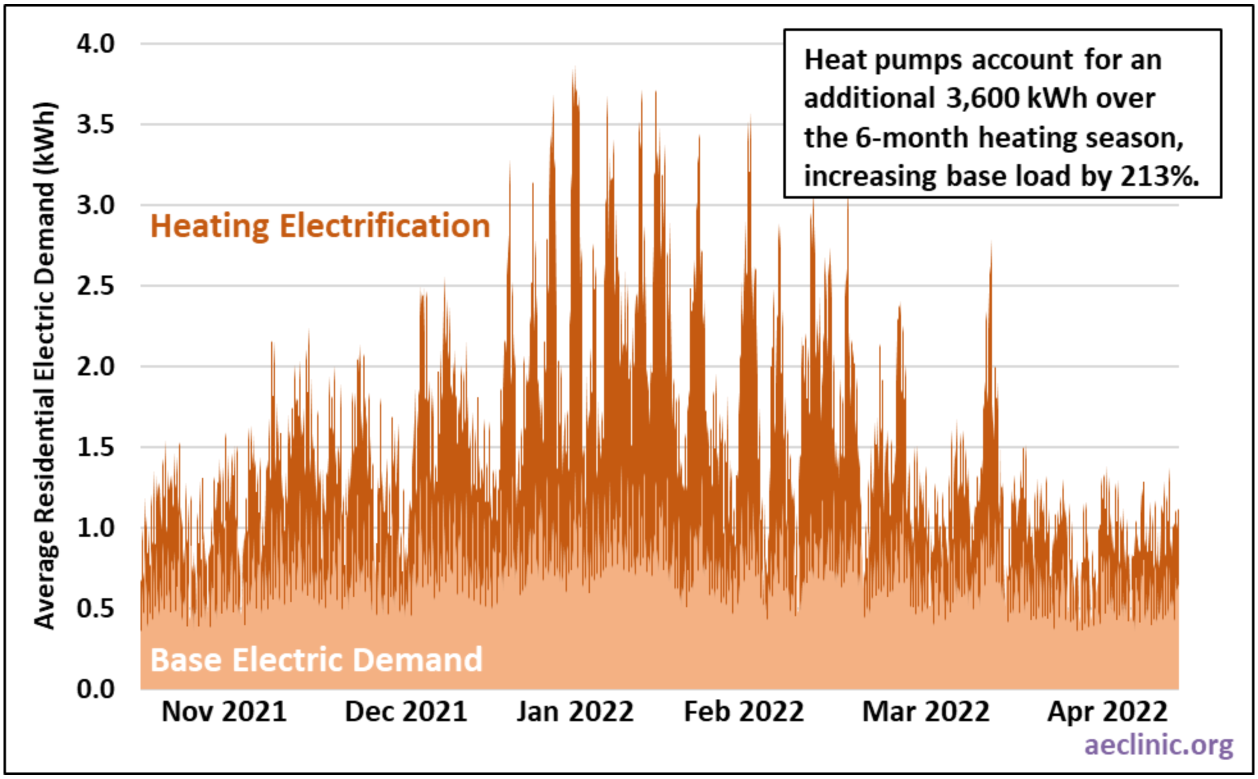
Current Massachusetts electric rates and rate structures are disadvantageous to building decarbonization policy and heating electrification efforts. The financial penalty created by the operating cost gap between gas-fired heating and ASHPs exacerbates the disproportionate energy burden experienced by low- to moderate-income households. To avoid creating a financial penalty, the DPU along with electric distribution companies must determine the appropriate electric rates and rate structures required to make heating electrification a cost-effective option for all households and businesses. Achieving Massachusetts' ambitious climate goals will require rate designs tailored to heating electrification.

Heat pump adoption shifts the electric system as a whole

Widespread adoption of heating electrification will have a profound effect on the electric system, both increasing and shifting peak electric demand. More electricity will be needed to heat homes and businesses with heat pumps, that demand will have a different pattern across hours of the day and days of year, and impacts of reliability failures (loss of winter heating) will also change.

For an average residential customer in Massachusetts, base (non-heating) electric demand represents nearly 3,200 kWh over the 6-month heating season with 31 percent (or 980 kWh) occurring during peak hours and 69 percent (or 2,200 kWh) during off-peak hours. Space heating with ASHPs requires an additional 3,600 kWh over the 6-month heating season, more than doubling base (non-heating) electric demand in those 6-months and raising it by 154 percent for the year in total (see Figure 5 below, where the light orange area represents base electric demand (i.e., without electrified heating) and the darker orange area represents the additional electric demand due to heating electrification). Heating electrification causes total electric demand (i.e., heating and non-heating combined) to shift towards off-peak hours with 74 percent of electric demand compared to the 69 percent of hours for base (non-heating) usage.

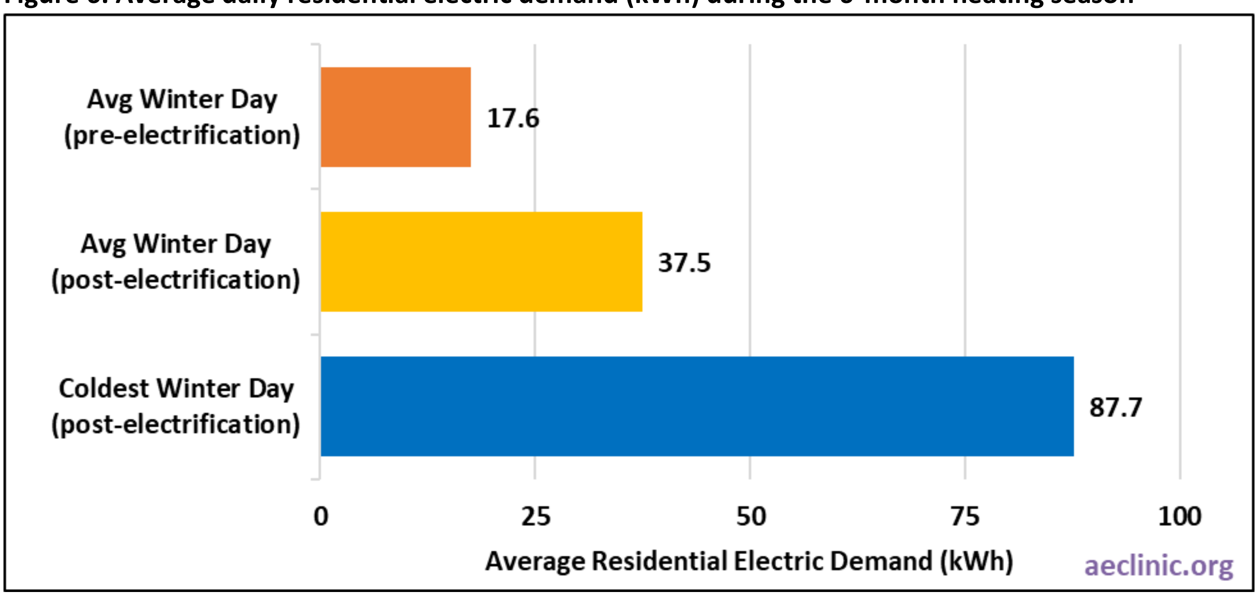
Figure 5. Impact of heating electrification on electric demand (kWh) of average customer in Massachusetts



Data source: AEC calculations, see Methodology Appendix for description of calculations and data sources.

Today, the average Massachusetts home uses 12.0 to 24.4 kWh each winter day (or 17.6 kWh on average); with home heating electrification that demand would rise to 37.5 kWh on the average winter day and up to 87.7 kWh on the coldest days (see Figure 6). Massachusetts' peak electric demand currently occurs on hot summer days; over time heating electrification is likely to shift that peak to the coldest days in winter.

Figure 6. Average daily residential electric demand (kWh) during the 6-month heating season



Data source: AEC calculations, see Methodology Appendix for description of calculations and data sources.

The 2025/30 CECP discusses the need for investments in the grid to accommodate electric system peak shifting from summer to winter due to heating electrification:

> *As electric heat pumps become more prevalent for space heating (and cooling), electricity demand in the winter is expected to grow, eventually shifting the system's peak from summer to winter. Such changes in electricity demand will require investment in the grid. The simulations show that electric space heating will not drive system peak until after 2030. However, since transmission development requires at least ten years of planning, design, siting, and deployment, it is important to incorporate the anticipated growth into today's transmission system planning.*[35]

IV. Alternative Rate Designs for Electrified Space Heating

Customer electric bills are the sum of several categories of supply and delivery charges. In Massachusetts, the basic service charge ($ per kWh) covers supply costs, renewable portfolio standard (RPS) compliance costs, and administrative costs.[36] Delivery charges include a fixed monthly customer charge ($ per month) as well as volumetric charges ($ per kWh) such as transmission, distribution, operations and service, and public policy (e.g., energy efficiency, renewable energy, etc.) charges.[37]

The design and structure of electric rates—the balance of basic service versus fixed charges versus volumetric delivery charges—can be tailored to reflect the costs specific to each customer class (e.g., residential, commercial, industrial) or end-use (e.g., electric vehicle charging, electric heating, etc.). In designing customer rates, electric distribution companies set both fixed and volumetric charges sufficient to recover costs associated with the supply and delivery services provided.

Some rate designs that are uncommon today, however, could be employed when setting rates for customers who have ASHPs; potential designs include but are not limited to:

- **Demand charges:** A demand charge is a fee based on the highest amount of energy the customer uses in a specific interval (typically 15, 30, or 60-minutes long) during a billing period (typically, one month).[38] The higher the customer's peak consumption during the demand interval the greater the demand charge, which is included on monthly electric bills in dollars per kilowatt ($ per kW).[39] Demand charges allow electric distribution companies to recover costs associated with building a distribution system with the capacity needed to meet peak aggregate customer demand. Although they are not historically utilized for residential electric customers, demand charges are a potential tool for incentivizing customers to consider not only how much electricity they consume (in kWh) but also their peak electric usage (in kW).

[35] Massachusetts Executive Office of Energy and Environmental Affairs. 2022. *Massachusetts Clean Energy and Climate Plan for 2025 and 2030*. Available at: https://www.mass.gov/doc/clean-energy-and-climate-plan-for-2025-and-2030/download p.72

[36] Massachusetts Department of Public Utilities (DPU). Accessed August 31, 2023. "Basic service information and rates." Available at: https://www.mass.gov/info-details/basic-service-information-and-rates

[37] Massachusetts Department of Public Utilities (DPU). Accessed November 28, 2023. "Understanding your Utility Bill." Available at: https://www.mass.gov/info-details/understanding-your-utility-bill

[38] Massachusetts Office of Technical Assistance and Technology (OTA). N.d. "Understanding Your Electric Bill: Saving Money on Demand Charges and Power Factor." Executive Office of Energy and Environmental Affairs (EEA). Available at: https://www.mass.gov/doc/understanding-your-electric-bill-saving-money-on-demand-charges-and-power-factor0/download. p.1.

[39] Ibid.

- **Time-of-use (TOU) pricing:** Also referred to as time variable rates (TVR), TOU pricing is an electric rate structure charging different rates at different times of day, typically defined by on- and off-peak hours. A TOU rate structure can be applied to any rate component, such as supply, delivery, and/or demand charges. TOU pricing allows electric suppliers to send price signals to consumers to better manage demand on the electric grid, for example, signaling customers to lower electric use by placing a higher rate at peak times. Higher TOU rates for times of peak electric usage help incentivize customers to shift electric demand to less expensive, off-peak hours.

Although some electric distribution companies—including Eversource in Massachusetts—have a separate rate class for residential space heating customers, most do not employ rate design mechanisms like demand charges or TOU pricing for this specific end-use. However, TOU pricing is being used for general residential customers in other jurisdictions; AEC's non-exhaustive review identified a number of states that offer TOU pricing, such as Connecticut, Kentucky, Maryland, New Hampshire, North Carolina, South Carolina, and Vermont.[40] In addition to an optional residential rate class with TOU pricing on volumetric delivery charges, Kentucky Utility Company also offers an option for TOU pricing on demand charges to its residential customers.[41] In North and South Carolina, Duke Energy offers a voluntary residential rate class with a demand charge on top of TOU pricing on volumetric delivery charges.

In addition, other end-uses like electric vehicle charging can utilize alternative rate structures to make them more cost-effective for customers. In Massachusetts, National Grid offers an off-peak charging rebate (analogous to TOU pricing) to its electric vehicle charging customers.

In its November 2023 final report, the Massachusetts Grid Modernization Advisory Council (GMAC) discussed the utilization of alternative rate designs as part of its recommendations for the electric distribution companies' electric-sector modernization plans:

> *[A]lternative rate design proposals must: (1) be fair and equitable; (2) consider affordability; and (3) be informed by careful study of potential impacts on customers, including low- to moderate-income (LMI) customers and customers in environmental justice communities (EJCs) and disadvantaged communities.*[42]

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[40] (1) Eversource Connecticut. September 2023. "Summary of Connecticut Electric Rates." Available at: https://www.eversource.com/content/docs/default-source/rates-tariffs/ct-electric/ct-electric-rates.pdf; (2) Kentucky Utilities Company. July 2021. "Rates, Terms and Conditions for Furnishing Electric Service." Available at: https://psc.ky.gov/tariffs/Electric/Kentucky%20Utilities%20Company/Tariff.pdf; (3) Delmarva Power & Light Company. August 2023. "Maryland Electric Tariff." Available at: https://azure-na-assets.contentstack.com/v3/assets/blt47b6e332b18fb457/blt8cf9af5b7ced035f/MD_DPL_CURRENT_Rate_Schedule_TRANSMISSION_090123.pdf; (4) Eversource New Hampshire. August 2023. "2023 Summary of Electric Rates: New Hampshire." Available at: https://www.eversource.com/content/docs/default-source/rates-tariffs/nh-summary-rates.pdf; (5) Duke Energy Progress North Carolina. 2023. "Residential Service Time-of-Use Schedule R-TOUD." Available at: https://www.duke-energy.com/-/media/pdfs/for-your-home/rates/dep-nc/leaf-no-501-schedule-r-toud-ry1.pdf?rev=6243ad61a5f346ea91f54b3b6db1c704; (6) Duke Energy Progress South Carolina. 2023. "Residential Service Time-of-Use Schedule R-TOUD." Available at: https://www.duke-energy.com/-/media/pdfs/for-your-home/rates/dep-sc/leaf-no-501-schedule-r-toud.pdf?rev=1337513e60e94b549c954ac6fcf8b637; (7) Green Mountain Power. October 2022. "Residential Time-Of-Use Service Rate Schedule." Available at: https://greenmountainpower.com/wp-content/uploads/2016/09/Rate-11.pdf

[41] Kentucky Utilities Company. July 2021. "Rates, Terms, and Conditions for Furnishing Electric Service." Available at: https://psc.ky.gov/tariffs/Electric/Kentucky%20Utilities%20Company/Tariff.pdf

[42] Grid Modernization Advisory Council (GMAC). November 2023. *Observations and Recommendations of the Grid Modernization Advisory Council: Regarding the Electric Distribution Companies' Electric-Sector Modernization Plans.* Pursuant to G.L. c. 164, §§ 92B-92C. Available at: https://www.mass.gov/doc/gmac-final-report/download p.16

GMAC also recommended the exploration of TOU pricing over demand charges for residential customers:

> *To provide additional guidance through examples of specific rate design concepts, the GMAC recommends that: (1) based on concerns that they would reduce customers' ability to manage their bills and have disproportionate and adverse impacts on low-income ratepayers, alternative rate design proposals should avoid broadly imposing demand charges on residential customers; and (2) alternative rate design proposals should consider peak-time rebate programs that incentivize demand reduction.*[43]

Alternative rate mechanisms designed specifically for electric space heating customers could allow electric distribution companies to close the operating cost cap between electric and gas-fired heating technologies as well as eliminate the financial penalty associated with heating electrification. To better understand the implications of current electric rate designs, AEC performed an in-depth analysis of customer energy bills under different heating technology scenarios. This type of heat pump-specific quantitative analysis—presented together with transparent data sources, assumptions, methodology and caveats—is essential to clear the way for alternative rate structures that can incentivize the widespread ASHP adoption necessary to achieve Massachusetts' emission reductions targets without causing unintended consequences for customers.

V. Key Takeaways

Current Massachusetts electric rates and rate structures are disadvantageous to building decarbonization policy: Under today's rate designs, homes or businesses adopting ASHPs can expect to pay more in energy bills than those that update their gas heating systems. This operating cost gap imposes a financial penalty on customers and a barrier for ASHPs to be a cost-effective heating option at the scale needed to achieve Massachusetts' decarbonization goals for its buildings sector.

Alternative rate designs have the potential to close the operating cost gap between heating technologies, which would make ASHPs a cost-effective heating option relative to fossil-fuel heating systems like gas-fired furnaces. By exploring and implementing alternative rate designs, Massachusetts would be able to make ASHPs more attractive to consumers, which would stimulate the widespread adoption of electric heat pumps and support its decarbonization efforts in the buildings sector.

More research and analysis into ratepayer and system-wide impacts of different alternative rate designs are needed to identify which rate structure and rate values are most appropriate to stimulate heat pump adoption in Massachusetts. Although alternative rate designs are employed in other jurisdictions and contexts, it is important that the Massachusetts DPU work with electric distribution companies to construct a rate schedule that is tailored to the specific characteristics of households and businesses in the Commonwealth.

[43] Ibid.

Methodology Appendix

To evaluate the associated bill impacts of electrifying residential space heating in Massachusetts, AEC compared the total household energy costs under various rate structures. Costs include all fixed and variable costs that residential customers pay on their monthly gas and electric bills. This analysis was conducted for the 2021/22 heating season, which is defined as the 6-month period between November 2021 and April 2022.

Heating season energy usage

In general, heating season energy usage includes gas and electric usage for heating and non-heating end-uses from November through April. AEC's Heating Electrification Assessment Tool (AEC-HEAT) was utilized in this analysis to estimate the heating component of a residential customer's energy usage.[44]

Energy used for heating is often measured in the physical units in which it is delivered to homes and businesses (e.g., therms of gas, gallons of oil, kilowatt-hours of electricity)—a practice that makes it difficult to directly compare how much energy is used by different kinds of heating systems. The British thermal unit (Btu) serves as a universal measure of heating requirements (i.e., how much "heat" is needed to warm a building), allowing easy comparison across various fuel options. (Technically, a Btu is the quantity of heat required to raise the temperature of one pound of water by 1 degree Fahrenheit.) In New England, an average-sized home (1,645 square feet of heated space) requires 50.4 million Btus (abbreviated "MMBtu") of heat each year, regardless of the energy source that produces the heat.[45]

AEC-HEAT's calculations are conducted on a "per degree-hour" basis to estimate the corresponding heating requirement in a given year based on outdoor air temperature data[46] provided by the National Oceanic and Atmospheric Administration (NOAA).[47] AEC uses "degree-hour" as the unit to measure the temperature preponderance at various outdoor air temperatures for a specific location. In this analysis, a "degree-hour" is measured by multiplying the change in temperature required to reach a target indoor air temperature of 70 degrees Fahrenheit (°F) by the number of hours at each temperature level (in increments of 1°F from -9 to 60°F) that was observed at the Logan International Airport in Boston, Massachusetts over the 10-year period between 2013 and 2022. The temperature preponderance shares for each 1°F increment were used to distribute the total 50.4 MMBtu heating requirement among observed outdoor air temperature levels.

AEC calculated the per-hour heating requirements for each resource by dividing the "per degree-hour" heating requirement estimates by the 10-year annual average number of hours that Boston spent at each temperature level; these per-hour estimates were then matched with hourly outdoor air temperature data for the 2021/22 heating season to construct a time series of the hourly heating requirements for an average-sized home in Massachusetts.

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[44] Castigliego, J.R., and E. Seliga. 2023. *AEC's Heating Electrification Assessment Tool (AEC-HEAT)—Version 1.1 [Excel Workbook]*. Applied Economics Clinic. Prepared on behalf of Green Energy Consumers Alliance (GECA). Available at: https://aeclinic.org/publicationpages/12/2023/aecs-heating-electrification-assessment-tool-aec-heat

[45] U.S. Energy Information Administration (EIA). June 2023. *2020 Residential Energy Consumption Survey (RECS) Data* [Table CE3.2]. Available at: https://www.eia.gov/consumption/residential/data/2020/c&e/pdf/ce3.2.pdf

[46] Note that AEC's analysis utilizes NOAA's "dry bulb" outdoor air temperature observations collected using FM-15 reporting methods. Source: National Oceanic and Atmospheric Administration (NOAA). 2013-2022. *Local Climatological Data (LCD) for Boston Logan International Airport, MA US (Station ID: WBAN:14739).* Available at: https://www.ncei.noaa.gov/cdo-web/

[47] The methodology used by AEC's Heating Electrification Assessment Tool (AEC-HEAT) is based on a similar analysis created for Hartford, Connecticut. Source: Personal communication with Mike Simons, Abode Energy Management in February 2023.

For gas heating customers, AEC calculated the energy usage by multiplying the calculated hourly heating requirements by an efficiency rate for a new gas-fired furnace of 95 percent.[48]

Instead of efficiency rates, heat pump technologies have what is known as a coefficient of performance (COP):

- **Efficiency rate:** the net energy output for a given amount of consumed energy (i.e., some energy is lost in the conversion).
- **Coefficient of performance (COP):** the required amount of energy that is needed to yield the desired output.

The COP for air-source heat pumps (ASHPs) varies depending on the difference between indoor and outdoor air temperatures (i.e., lower COP for colder outdoor air temperatures and higher COP for warmer outdoor air temperatures).[49] AEC calculated the energy usage for electric customers with ASHPs by dividing the hourly heating requirements by the corresponding COP value for the outdoor air temperature at each hour.

Non-heating (i.e., other) end-uses include, but are not limited to, water heating, clothes dryers, cooking, lighting, refrigerators, air conditioners, among others. To estimate non-heating energy usage for gas customers, AEC calculated the share of total gas usage attributable to space heating (69 percent) and to other gas end-uses (31 percent) as reported by the U.S. Energy Information Administration's *2020 Residential Energy Consumption Survey* for the New England region;[50] This ratio is used to scale up the heating requirements from AEC-HEAT to estimate total gas use and therefore non-heating gas use.

As a proxy to estimate non-heating energy usage for electric customers, AEC utilized National Grid's Class Average Load Shapes[51] for residential customers in Massachusetts, which provides estimates of the amount of electricity (in kWh) the average customer in a particular rate class (i.e., R-1, Regular Residential) uses each hour of the year. Since space heating is only attributable to 9.5 percent of total electric usage in New England,[52] AEC considers National Grid's average residential load shapes to be an appropriate proxy for non-heating energy usage for electric customers in Massachusetts.

Heating and non-heating electric usage was further categorized into peak and off-peak usage by applying AEC's assumed peak window of 1pm to 9pm for weekdays (excluding holidays).[53]

Residential gas and electric rates in Massachusetts

AEC's analysis utilizes the most recent service and delivery rates for each of Massachusetts' gas and electric utilities (as of September 2023). For this analysis, AEC used average gas rates across all of Massachusetts' gas

[48] U.S. Energy Information Administration (EIA). March 2023. *Technology Forecast Updates - Residential and Commercial Building Technologies - Reference Case.* Available at: https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf. p.10

[49] Personal communication with Mike Simons, Abode Energy Management in February 2023.

[50] U.S. Energy Information Administration (EIA). June 2023. *2020 Residential Energy Consumption Survey (RECS) Data* [Table CE4.2]. Available at: https://www.eia.gov/consumption/residential/data/2020/c&e/pdf/ce3.2.pdf

[51] National Grid. June 2023. Massachusetts - Class Average Load Shapes. Available at: https://www9.nationalgridus.com/energysupply/load_estimate.asp

[52] U.S. Energy Information Administration (EIA). June 2023. *2020 Residential Energy Consumption Survey (RECS) Data* [Table CE4.2]. Available at: https://www.eia.gov/consumption/residential/data/2020/c&e/pdf/ce3.2.pdf

[53] AEC's assumed peak windows are based on those defined by National Grid's Off-Peak Charging Program in Massachusetts. Source: National Grid. July 2022. "National Grid Launches Off-Peak Electric Vehicle Charging Program for Massachusetts Customers." Available at: https://www.nationalgridus.com/News/2022/07/National-Grid-Launches-Off-Peak-Electric-Vehicle-Charging-Program-for-Massachusetts-Customers/

distribution companies, while electric costs were evaluated for each individual electric distribution company.

Massachusetts' gas rates were collected for each of the state's local distribution companies: National Grid, Eversource, Unitil, Liberty Utilities, and Berkshire Gas Company (see Table 2 for a summary of Massachusetts gas rates by utility). Gas rate components include the following charges and adjustment factors:

- **Supply Charges:**
  - Gas Adjustment Factor (GAF, $ per therm)
- **Delivery Charges:**
  - Fixed Monthly Customer Charge ($ per month)
  - Distribution Charge ($ per therm)
  - Revenue Decoupling Adjustment Factor (RDAF, $ per therm)
  - Local Distribution Adjustment Factor (LDAF, $ per therm)

Table 2. Summary of 2023 residential gas rates in Massachusetts by local distribution company

Local Distribution Company	Supply	Delivery	
	Cost of Gas Adjustment Factor ($ per therm)	Customer Charge ($ per month)	Total Delivery Charges ($ per therm)
National Grid	$0.882	$12.00	$1.206
Eversource	$0.902	$11.10	$1.138
Unitil	$0.362	$10.00	$1.924
Berkshire Gas Company	$0.974	$11.42	$0.954
Liberty Utilities	$1.017	$11.80	$0.808
Massachusetts Average	$0.828	$11.26	$1.206

Notes: *The rates provided in this table correspond to the average rates of R-3 residential gas heating customers across all service territories by each distribution company.* ***Sources:*** *(1) Massachusetts DPU Docket No. 23-PGAF-GRID. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Attachment B. Submitted by Boston Gas Company d/b/a National Grid. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17790614%20 pp.6-7; (2) Massachusetts DPU Docket No. 23-PGAF-NSTAR. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Section IV. Submitted by NSTAR Gas Company d/b/a Eversource Energy. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17793237%20 p.3; (3) Massachusetts DPU Docket No. 23-PGAF-EGMA. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Section 7. Exhibit EGMA-MQ-2. Submitted by Eversource Gas Company of Massachusetts d/b/a Eversource Energy. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17793081 p.3; (4) Massachusetts DPU Docket No. 23-PGAF-FGE. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Attachment A. Submitted by Fitchburg Gas and Electric Light Company d/b/a Unitil. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17790510 p.3; (5) Massachusetts DPU Docket No. 23-PGAF-BERK. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Form II. Submitted by The Berkshire Gas Company. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17811435 p.17; and (6) Massachusetts DPU Docket No. 23-PGAF-LIB. August 2023. Local Distribution Adjustment Clause Filing for November 1, 2023 through October 31, 2024. Form II. Submitted by Liberty Utilities (New England Natural Gas Company) Corp. d/b/a Liberty. Attachment 2. Schedule 1. Available at: https://fileservice.eea.comacloud.net/FileService.Api/file/FileRoom/17791574*

Massachusetts' electric rates were collected for each of the state's publicly-owned electric distribution companies: National Grid, Eversource, and Unitil (see Table 3 for a summary of Massachusetts electric rates by utility). Electric rate components include the following charges:

- **Supply Charges:**
    - Basic Service Charge ($ per kWh)
- **Delivery Charges:**
    - Fixed Monthly Customer Charge ($ per month)
    - Distribution Charge ($ per kWh)
    - Transmission Charge ($ per kWh)
    - Transition Charge ($ per kWh)
    - Energy Efficiency Charge ($ per kWh)
    - Renewable Energy Charge ($ per kWh)
    - Distributed Solar Charge ($ per kWh)
    - Among other charges

Table 3. Summary of 2023 residential electric rates in Massachusetts by electric distribution company

Electric Distribution Company	Supply	Delivery	
	Basic Service Charge ($ per kWh)	Customer Charge ($ per month)	Total Delivery Charges ($ per kWh)
National Grid	$0.141	$7.00	$0.158
Eversource	$0.157	$10.00	$0.149
Unitil	$0.212	$7.00	$0.206

Notes: *The rates provided in this table correspond to the average rates of R-1 residential electric customers across all service territories by each distribution company. Eversource also provides service to residential space heating customers in its R-3 rate class; these rates are identical to Eversource's R-1 rates except for the total delivery charges of $0.144 per kWh on average.* ***Sources:*** *Supply Charges: Massachusetts Department of Public Utilities. Accessed August 31, 2023. "Basic service information and rates." Available at: https://www.mass.gov/info-details/basic-service-information-and-rates. Delivery Charges: (1) National Grid. 2023. "Tariff Provisions: Summary of Electric Delivery Service Rates." M.D.P.U. No. 1-23-F. Available at: https://www.nationalgridus.com/MA-Home/Rates/Tariff-Provisions; (2) Eversource. 2023. "Tariff Provisions: Summary of Electric Delivery Service Rates." M.D.P.U. No. 1-23-D. Available at: https://www.eversource.com/content/docs/default-source/rates-tariffs/ma-electric/1-tariff-ma.pdf?sfvrsn=2c5b9f03_7; and (3) Unitil. 2023. "Massachusetts Residential Electric Rates." Available at: https://www.unitil.com/sites/default/files/2023-08/MA_Elect_Residential_Rates_0823.pdf*