AEC's Heating Electrification Assessment Tool: User Guide and Methodology

AEC-HEAT

Prepared on behalf of Green Energy Consumer Alliance (GECA)

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Version 1.1

Applied Economics Clinic

Economic and Policy Analysis of Energy, Environment and Equity

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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. 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 past four 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 its full-time and part-time 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.

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I. AEC-HEAT User Guide

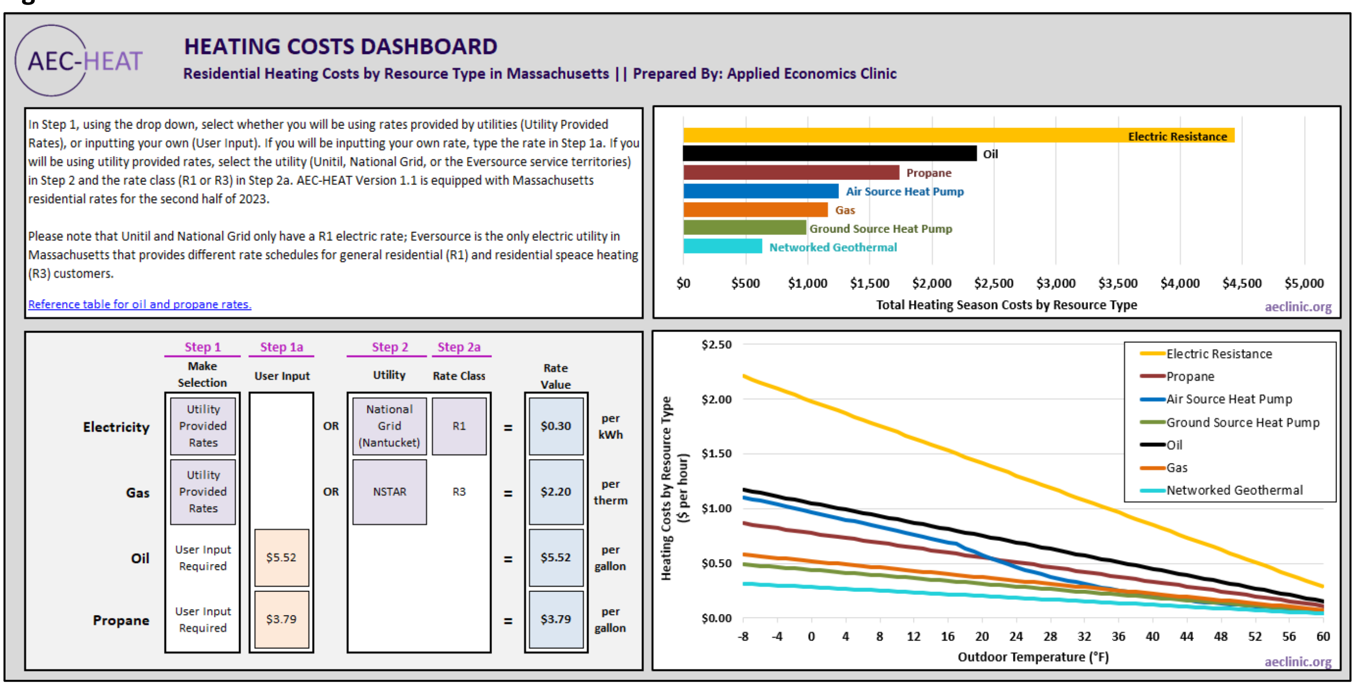
The Applied Economics Clinic's (AEC) Heating Electrification Assessment Tool (AEC-HEAT) (1) compares heating costs for various resource types and (2) evaluates the impact of new space heating electrification on regional peak electric use during the winter heating season. AEC-HEAT Version 1.1 is currently equipped to perform assessments specific to Massachusetts but has the ability to evaluate other jurisdictions pending data availability (see Section II below for specific data requirements).

AEC-HEAT is a spreadsheet-based tool that houses two *Dashboard* tabs (i.e., Heating Costs Dashboard and Load Profile Dashboard) to provide users with an interface to evaluate impacts associated with space heating electrification. Users can customize the tool by selecting parameters from drop-down menus or inputting their own data values.

Heating Costs Dashboard

The Heating Costs Dashboard provides users with a chart of total heating season costs for the different resource types as well as a chart comparing heating costs by resource type (in $ per degree-hour) against a range of outdoor air temperatures (in degrees Fahrenheit) (see Figure 1).

Figure 1. AEC-HEAT Heat Costs Dashboard

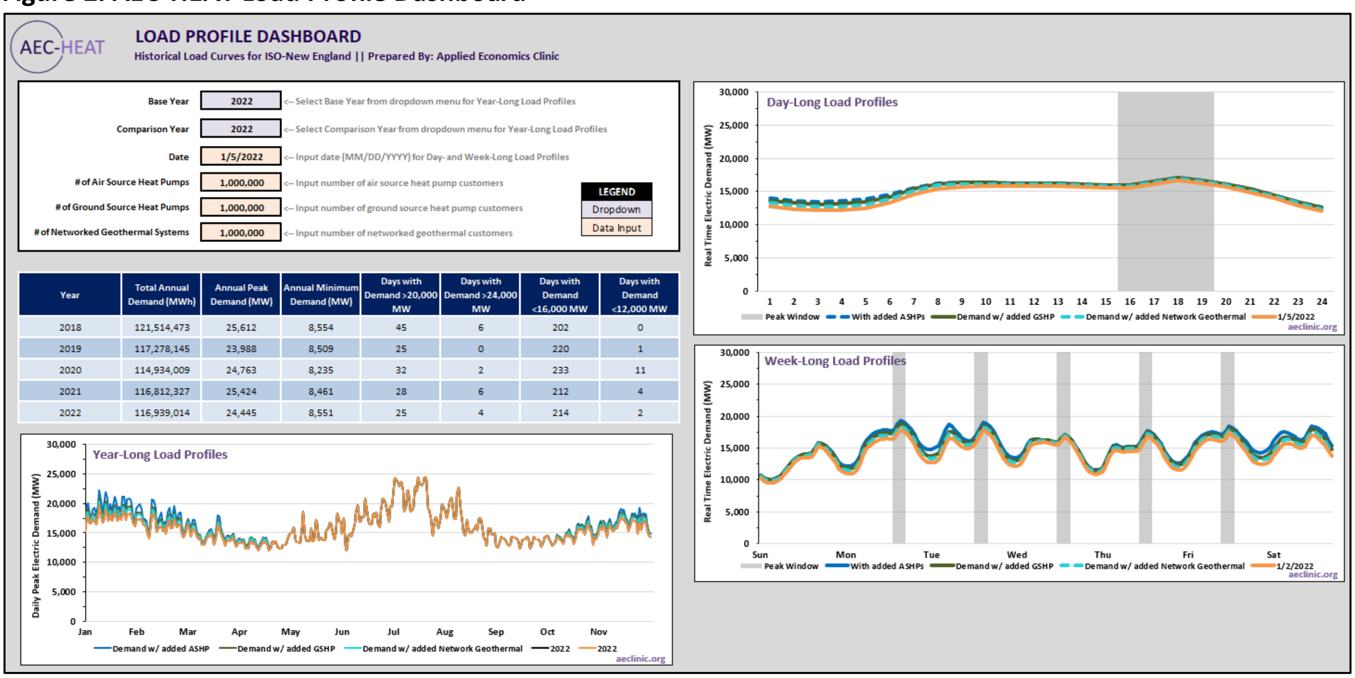


To assess the heating costs among different resource types, users are able to select utility provided rates (AEC-HEAT Version 1.1 is equipped with Massachusetts residential rates for the second half of 2023) or input their own rates, for example potential future rates for individual resources or specific rates currently provided by municipal utilities or community choice aggregation programs. To enter rates for electricity, gas, oil, and propane, users must first select whether they intend to use utility provided rates or input their own in Step 1, then users can either input their own rates in Step 1a or choose a specific utility and corresponding rate class in Steps 2 and 2a. (See Section II below for the data, assumptions, and methodology used for the Heating Costs Dashboard.)

Load Profile Dashboard

The Load Profile Dashboard provides users with a table of summary statistics as well as separate charts to visualize day-, week-, and year-long load profiles based on selected parameters (see Figure 2). The summary statistics table offers users a snapshot of how regional electric use (AEC-HEAT Version 1.1 used data for the ISO-New England region) compares historically from year to year. For the year-long load profiles, users can select a base year and comparison year to visually assess the differences between daily peak energy demand for each year (in megawatts (MW)). The day- and week-long load profiles are generated from the user-inputted date (in MM/DD/YYYY format) and show the hourly real-time demand as well as applicable peak windows as defined by the Massachusetts Clean Peak Standard (CPS). The day-, week-, and year-long load profiles also allow users to analyze the load impacts associated with space heating electrification using air-source heat pumps (ASHPs), ground-source heat pumps (GSHPs), or networked geothermal systems by entering the number of households heated by these technologies. (See Section II below for the data, assumptions, and methodology used for the Load Profile Dashboard.)

Figure 2. AEC-HEAT Load Profile Dashboard



Year	Total Annual Demand (MWh)	Annual Peak Demand (MW)	Annual Minimum Demand (MW)	Days with Demand >20,000 MW	Days with Demand >24,000 MW	Days with Demand <16,000 MW	Days with Demand <12,000 MW
2018	121,514,473	25,612	8,554	45	6	202	0
2019	117,278,145	23,988	8,509	25	0	220	1
2020	114,934,009	24,763	8,235	32	2	233	11
2021	116,812,327	25,424	8,461	28	6	212	4
2022	116,939,014	24,445	8,551	25	4	214	2

II. Methodology

Massachusetts Residential Heating Cost Analysis

The residential heating cost analysis for Massachusetts aims to provide AEC-HEAT users with the ability to compare heating costs of different resource types, including gas, oil, propane, electric resistance, air-source heat pumps (ASHPs), ground-source heat pumps (GSHPs), and networked geothermal systems.

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.[1]

AEC's heating cost analysis was conducted on a "per degree-hour" basis to estimate the corresponding heating requirement in a given year based on outdoor air temperature data[2] provided by the National Oceanic and Atmospheric Administration (NOAA).[3] AEC uses "degree-hour" as 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) 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. Using these heating requirements on a "per degree-hour" basis, AEC calculated the energy usage and heating costs for each resource type (see calculation descriptions below). AEC then calculated the per-hour heating requirements and heating costs 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 each year to construct the heat pump load curves discussed in the *New England Load Profile Analysis* subsection below.

To estimate residential heating costs in Massachusetts by resource type, AEC first calculated the energy usage for gas, oil, propane, and electric resistance by multiplying the heating requirement for an average New England home of 50.4 MMBtu by the corresponding efficiency rate (i.e., 95 percent for gas, 86 percent for oil,

[1] U.S. Energy Information Administration. 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

[2] 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/

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

80 percent for propane, and 100 percent for electric resistance).[4]

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.

AEC calculated the energy usage for ASHPs, GSHPs, and networked geothermal systems by dividing the average heat requirement of 50.4 MMBtu by the COP for each technology. The COP for 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).[5] Since GSHPs and networked geothermal systems rely on temperature differences within the ground, the COPs for these technologies are more consistent across different outdoor air temperatures compared to ASHPs (see Figure 3). AEC assumes GSHPs[6] and networked geothermal[7] to have COPs of 4.5 and 7.0, respectively. (Note that the COP for networked geothermal is an average based on data provided by The GreyEdge group.)

Energy usage in MMBtu was converted to the following physical units for each resource: therms for gas, gallons for oil and propane, and kilowatt-hours (kWh) for electric resistance, ASHPs, GSHPs, and networked geothermal systems. AEC then estimated residential heating costs in Massachusetts by multiplying the energy usage (in physical units) by the corresponding residential rate ($ per physical unit) for each resource. Residential oil and propane rates[8] for New England were sourced from the U.S. Energy Information Administration, while gas and electric rates[9] were compiled from Massachusetts' electric and gas distribution companies. Fixed charges paid on electric bills were excluded from AEC's analysis since households already use electricity for other end-uses

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[4] (1) Gas is assumed to have an efficiency rate of 95 percent based on that of a new gas furnace. Source: M.J. Bradley & Associates, LLC. 2019. Life Cycle Analysis of the Northeast Supply Enhancement Project. Available at: https://www.mjbradley.com/sites/default/files/MJBA_NESE_LCA_06112019.pdf; (2) The efficiency rates for oil (86 percent) and propane (80 percent) were based on federal minimum standards. Source: American Council for an Energy Efficient Economy. 2018. Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air Source Heat Pumps. Available at: https://www.aceee.org/sites/default/files/publications/researchreports/a1803.pdf; (3) Electric resistance is assumed to have an efficiency rate of 100 percent. Source: U.S. Department of Energy (DOE). n.d. "Electric Resistance Heating." Available at: https://www.energy.gov/energysaver/home-heating-systems/electric-resistance-heating

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

[6] Based on the reported efficiency conversion factor of 65.1 kWh per MMBtu (i.e., 293.1 divided by 65.1 equals a COP of 4.5). Source: M.J. Bradley & Associates, LLC. 2019. *Life Cycle Analysis of the Northeast Supply Enhancement Project.* Available at: https://www.mjbradley.com/sites/default/files/MJBA_NESE_LCA_06112019.pdf

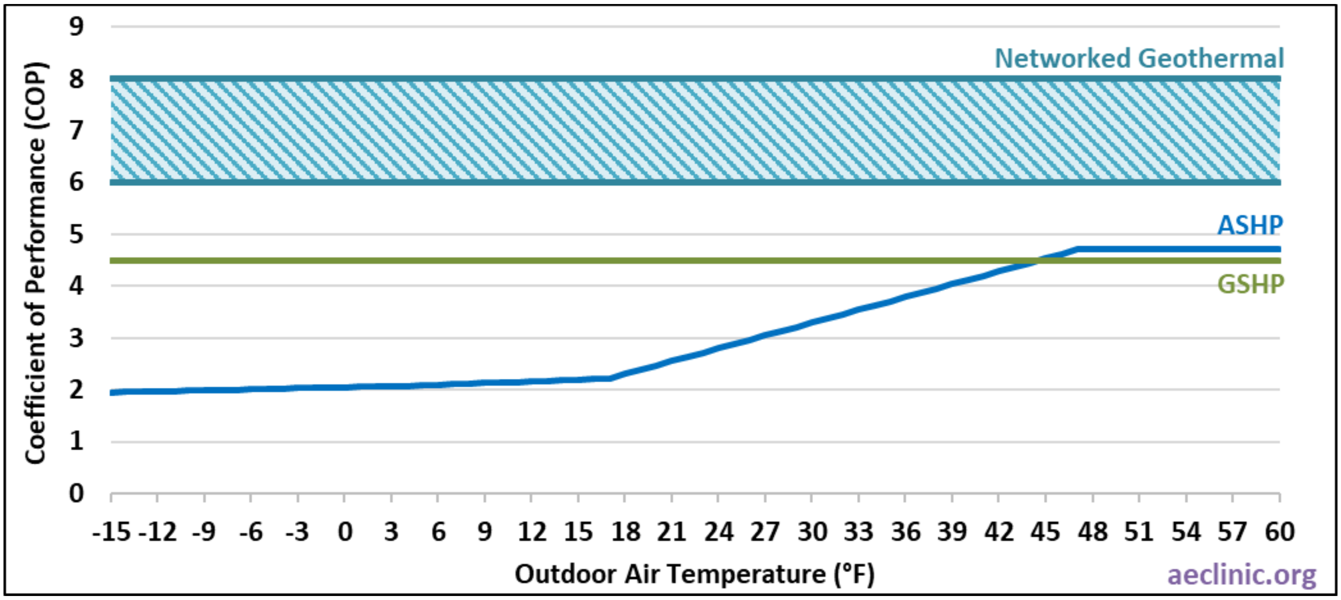
[7] AEC Assumption based on data provided by The GreyEdge Group.

[8] U.S. Energy Information Administration. 2023. "Petroleum & Other Liquids." Available at: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=M_EPLLPA_PRS_R1X_DPG&f=M

[9] Massachusetts residential electric rates include supply and delivery charges for the following electric distribution companies: Unitil, National Grid, and Eversource (Greater Boston, Cambridge, Cape Cod, South Shore, and West service territories). Massachusetts residential gas rates include the monthly customer charge, energy charge Revenue Decoupling Adjustment Factor (RDAF), Gas Adjustment Factor (GAF), Local Distribution Adjustment Factor (LDAF), and Gas System Enhancement Program (GSEP) charge for the following gas distribution companies: Unitil, National Grid, Eversource, Liberty Utilities, and Berkshire Gas Company.

and, therefore, switching to electric heating does not add or increase these fixed charges. Fixed charges for gas use, however, are included in the analysis; households that stop using gas to heat their homes no longer pay gas fixed charges. The monthly fixed customer charge for gas customers was converted to a per therm basis by dividing by monthly average residential gas use (approximately 112.5 therms) for heating customers in Massachusetts during the heating season.[10]

Figure 3. Coefficient of performance (COP) for ASHP, GSHP, and networked geothermal



New England Load Profile Analysis

To display the day-, week-, and year-long load profiles for New England, the Load Profile Dashboard relies on ISO-New England's real-time hourly electric demand data for 2018 through 2022.[11] These load profiles are used as a baseline to assess the additional load in October through March (i.e., the heating season) presented by space heating electrification using ASHPs, GSHPs, and networked geothermal systems. This analysis excludes the impacts in April through September (i.e., the cooling season) associated with the cooling benefits provided by heat pumps and networked geothermal systems.

[10] Mass.gov. n.d. "Understanding your Utility Bill." Available at: https://www.mass.gov/info-details/understanding-your-utility-bill#:~:text=While%20the%20average%20residential%20non,you%20use%20in%20your%20home.

[11] ISO-New England. 2018-2022. "Standard Market Design (SMD) Hourly Data." Available at: https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/zone-info

As described above in the *Massachusetts Residential Heating Cost Analysis* subsection, AEC estimated the energy demand required by ASHPs, GSHPs, and networked geothermal systems on a per hour basis and applied those calculations to hourly outdoor air temperature data measured by NOAA at the Logan International Airport in Boston, Massachusetts. These calculations represent the additional electric demand required to heat a single household during the heating season for each technology. AEC-HEAT allows users to evaluate the impact of ASHPs, GSHPs, and networked geothermal systems on regional electric use by inputting the number of households that will adopt each of these technologies. With that information, AEC-HEAT is able to calculate the resulting day-, week-, and year-long load profiles for New England if these technologies additions were implemented.

The day- and week -long load profiles for New England also display the peak windows for each season as defined by the Massachusetts Clean Peak Standard (CPS) (see Table 1).[12]

Table 1. Peak windows as defined by the Massachusetts Clean Peak Standard (CPS)

Cleak Peak Season	Season Dates	Peak Windows
Winter	Dec 1 - Feb 28	4pm - 8pm
Spring	Mar 1 - May 14	5pm - 9pm
Summer	May 15 - Sep 14	3pm - 7pm
Fall	Sep 15 - Nov 30	4pm - 8pm

[12] Massachusetts Regulations Title 225 (2020). 225 CMR 21.00: Clean Peak Energy Portfolio Standard (CPS). Available at: https://www.mass.gov/doc/225-cmr-21-clean-peak-energy-portfolio-standard-cps/download