PowerHouse™

Approach, Rationale, and Methodology

Spring 2021

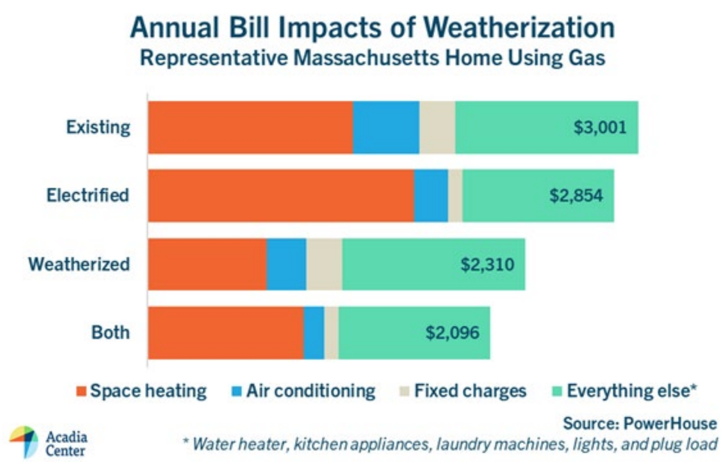
Advancing the Clean Energy Future

Approach and Rationale

PowerHouse™ is a home energy simulator, developed by Acadia Center, which demonstrates the positive consumer economics and greenhouse gas impacts of zero-emissions-ready residential retrofits. PowerHouse shows, with a high degree of detail, how different clean energy upgrades affect energy bills and household emissions in a range of housing types. Combining ten years of temperature and humidity data for nine locations in the Northeast U.S. and eight residential building typologies, the simulator is capable of **modeling 720 separate scenarios using its default inputs.**

The tool can be tailored to specify a range of building characteristics: building shell component efficiencies, heated square footage, average ceiling height, fenestration details, HVAC configuration, rooftop solar array kilowatts, thermostat set points, and other factors, making the tool capable of simulating energy and emissions impacts for **thousands of different home configurations.**

This analytical capability—at once **both hyper-local and wide-ranging**—can convincingly show how whole-home electrification, weatherization upgrades, and rooftop solar installation can eliminate emissions while saving money for building occupants.



Scenario Analysis

PowerHouse simulates energy and emissions impacts for residential single-family and low-rise multifamily building typologies. Because larger multifamily buildings generally use equipment that is more analogous to a commercial building, energy efficiency programs and other state policy instruments commonly treat them as part of the commercial sector; they are not included in this residential tool.

The model calculates thermal loads for each building component, for each hour of the year, as a function of outdoor temperature and humidity. **Evaluating a building's thermal needs on an hourly basis provides two important insights:**

- First, it allows the model to closely adjust heat pump performance expectations based on outdoor temperature, humidity, and occupant behavior, leading to a **highly accurate assessment of the influence of fluctuations in weather** on home heating and air conditioning costs after electrification.

Setting	Typology
Single-family	One-story Ranch
	1.5-story Cape
	Two-story Colonial
	Three-story town home
Multi-family	Row house: single unit
	Row house: two units
	Three-decker
	Mixed use: four units

- Second, it allows for a detailed forecast of heat pump power draw during peak conditions on the electric grid, providing **valuable information about how weatherization and flexible load can be used to mitigate the winter peak impacts** of building electrification in the Northeast.

Additionally, evaluating the effects that weatherization improvements can have on a building's heating and air conditioning needs provides a detailed look at the **compounding benefits of delivering comprehensive, whole-home retrofits.**

Finally, rooftop solar generation potential is also integrated into the simulator, allowing for a close look at how to deliver **home energy retrofits that are truly net-zero.**

Methodology

Thermal Loads and Heat Pump Performance

The simulator calculates the heat losses and gains attributable to each building shell component using the area and insulation R-value[1] of the component and the weather in a given hour. Similar calculations are performed to assess air infiltration, latent load,[2] and internal gains.[3] All of these thermal load estimates are evaluated as a function of outdoor temperature or humidity. ACCA Manual *J* algorithms are leveraged for this purpose. Comparisons between two of the range of different building shell efficiency tiers included in the simulator **allow for an analysis of the impacts of weatherization improvements of varying depth.**[4]

Cold-climate air-source heat pump ratings data derived from Northeast Energy Efficiency Partnership's (NEEP) air-source heat pump qualified products list were used to develop **three heat pump performance curves:** one for efficiency using COP or SEER, one for power draw in Watts per BTU, and one for heating capacity as a percentage of rated capacity at 47°F (i.e. "maintenance capacity"). Ratings from the NEEP list are modestly discounted to reflect metering data[5] which has shown that real-world heat pump performance tends to slightly lag performance measured in a Department of Energy test procedure.

The simulator **applies the heat pump performance curves to the building's heating or air conditioning requirement in a given hour** to calculate the amount of electricity that the heat pump can be expected to use. In situations where the model identifies a shortfall in heating capacity on the part of the heat pump, it assumes that backup electric resistance heat covers the differential between what the heat pump can supply and what the home needs in order to remain at a given thermostat set point.

Energy Use by Other Equipment

In addition to heating and air conditioning equipment, the model home contains a water heater, a refrigerator, a dishwasher, an oven and cooktop, a microwave, a clothes washer and dryer, a television, a computer, a ceiling fan,

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[1] The R-value of other shell components like cladding, siding, drywall, and asphalt shingles are also accounted for.

[2] Broadly, latent load refers to the stress on air conditioning equipment arising from its dehumidification function.

[3] Internal gains refer to the heat that building occupants, water heating equipment, kitchen and laundry appliances, and the sun contribute to a building.

[4] The model's shell efficiency tiers are designed to account for limitations in what can be achieved through weatherization improvements. For example, above-grade wall R-values are set in such a way as to reflect the difficulty of reaching R-20 wall insulation in a home with 2x4 walls or lath & plaster.

[5] Maine Climate Council Buildings, Infrastructure, & Housing Working Group: Efficiency Maine Trust Intro Heat Pumps Slides
Cadmus Group, Inc. "Evaluation of Cold Climate Heat Pumps in Vermont." November 3, 2017. Page 24.

and 30 light bulbs. Consumption estimates for these energy users were taken primarily from the Energy Information Administration's Residential Energy Consumption Survey (RECS). Energy use from high-efficiency electric equipment was assessed in the following ways:

- Heat pump water heater energy use in kWh/year was derived through an analysis of AHRI data.
- Ventless heat pump dryer energy use in kWh/year was taken from the ENERGY STAR efficient products list.
- Induction range energy use in kWh/year was directly calculated using cooktop efficiency estimates from a 2014 ACEEE study, coil-surface electric range consumption estimates from RECS, and assumptions about the frequency and duration of stove-top and oven cooking for a family of four.

Fuel Prices and Electric Rates

Energy prices are taken from EIA data[6] and from the most recent investor-owned utility tariffs for each electric or natural gas utility operating in New England, New York, or New Jersey.[7] For fossil fuels, prices are set by taking the average of the fuel's residential retail price in all winter months for the five years between 2014 and 2019. Statewide average annual electric rates are used in the default analysis, but utility-specific or seasonal electric rates can be substituted as needed. The year 2020 is currently excluded from the analysis out of an expectation that it will remain an outlier due to the economic impacts of the COVID-19 pandemic.

Weather

Weather data is taken from the National Centers for Environmental Information (NCEI), part of the National Oceanic and Atmospheric Administration (NOAA). Temperature and humidity data for each hour of each year between 2010 and 2019 is available for analysis.

State	Location	Design Temperatures (°F)	
		Heating	Cooling
Connecticut	Hartford Brainard Field	6.4	90.5
Maine	Bangor International Airport	-7.4	87.8
Massachusetts	Logan International Airport	7.4	90.8
New Hampshire	Manchester Airport	1.0	91.2
New Jersey	Trenton Mercer Airport	9.8	92.6
New York	LaGuardia Airport	12.6	92.2
New York	Rochester Greater International	2.1	88.4
Rhode Island	Providence	7.2	90.1
Vermont	Burlington International Airport	-8.3	88.3

Heating and air conditioning design temperatures are taken from Chapter 14 of the 2017 ASHRAE Handbook. The model uses ASHRAE's 99.6% heating design temperature and 0.4% cooling design temperature for each location. The simulator uses these data to calculate design loads for heating and air conditioning equipment, which in turn determines the model's installation cost estimates.

[6] EIA: Heating Oil and Propane Update and Natural Gas data.

[7] **Electric utilities:** Eversource and United Illuminating (CT); Central Maine Power and Emera (ME); Eversource, National Grid, and Unitil (MA); Eversource, Liberty Utilities, and Unitil (NH); Atlantic City Electric, Jersey Central Power & Light, PSEG, and Rockland Electric (NJ); Central Hudson Gas & Electric, ConEd, National Grid, New York State Electric & Gas, Orange & Rockland, and Rochester Gas & Electric (NY); National Grid (RI); and Green Mountain Power (VT).
Gas utilities: Connecticut Natural Gas, Yankee Gas, and Southern Connecticut Gas (CT); Bangor Natural Gas, Maine Natural Gas, Summit Natural Gas, and Northern Utilities (ME); Berkshire Gas, Blackstone Gas, Eversource, Liberty Utilities, National Grid, and Unitil Gas (MA); Liberty Utilities and Northern Utilities (NH); Elizabethtown Gas, New Jersey Natural Gas, PSEG, and South Jersey Gas (NJ); Central Hudson Gas and Electric, ConEd, Corning Gas, National Grid, National Fuel, New York State Electric & Gas, Orange & Rockland, St. Lawrence Gas, and Valley Energy (NY); National Grid (RI); and Vermont Gas (VT).