



Opinion **Dynamics**

VERMONT CLEAN HEAT STANDARD TRM

FINAL
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TABLE OF CONTENTS

| | |
|--|------------|
| 1. Overview | 5 |
| 1.1 Purpose of the TRM | 5 |
| 1.1.1 Applying the CHS TRM | 5 |
| 1.1.2 Deemed Savings | 5 |
| 1.2 Glossary | 5 |
| 1.3 TRM Assumptions | 7 |
| 1.3.1 Documentation of Sources | 7 |
| 1.3.2 Lifecycle Emissions Schedule | 7 |
| 1.3.3 Transmission and Distribution Losses and Carbon Intensity Adders | 15 |
| 1.4 Custom Measures | 15 |
| 2. Commercial/Industrial Installed Measures | 17 |
| 2.1 Appliances | 17 |
| 2.1.1 Heat Pump Clothes Dryers | 17 |
| 2.1.2 Induction Cooktop | 24 |
| 2.2 Building Envelope | 28 |
| 2.2.1 Air Sealing | 28 |
| 2.2.2 Building Shell Insulation | 34 |
| 2.3 Domestic Hot Water | 41 |
| 2.3.1 Heat Pump Water Heater | 41 |
| 2.3.2 Low Flow Faucet Aerator | 49 |
| 2.3.3 Low Flow Showerhead | 55 |
| 2.3.4 Solar Water Heater | 60 |
| 2.4 HVAC | 66 |
| 2.4.1 Advanced Thermostats | 66 |
| 2.4.2 Advanced Wood Heating – Central Pellet Systems | 73 |
| 2.4.3 Advanced Wood Heating – Pellet Stoves | 78 |
| 2.4.4 Air Source Heat Pump – Full Displacement | 83 |
| 2.4.5 Air Source Heat Pump – Partial Displacement | 89 |
| 2.4.6 Air-to-Water Heat Pumps | 95 |
| 2.4.7 Ground Source Heat Pump | 100 |
| 2.4.8 Variable Refrigerant Flow (VRF) Heat Pump Systems | 107 |
| 2.5 Miscellaneous | 112 |
| 2.5.1 Heat Pump Pool Water Heater | 112 |
| 3. Residential Installed Measures | 117 |
| 3.1 Appliances | 117 |
| 3.1.1 Heat Pump Clothes Dryers | 117 |
| 3.1.2 Induction Cooktop | 124 |

| | | |
|-----------|--|------------|
| 3.2 | <i>Building Envelope</i> | 128 |
| 3.2.1 | Air Sealing | 128 |
| 3.2.2 | Building Shell Insulation..... | 135 |
| 3.3 | <i>Domestic Hot Water</i> | 143 |
| 3.3.1 | Heat Pump Water Heater | 143 |
| 3.3.2 | Low Flow Faucet Aerator | 149 |
| 3.3.3 | Low Flow Showerhead | 155 |
| 3.3.4 | Solar Water Heater | 160 |
| 3.4 | <i>HVAC</i> | 165 |
| 3.4.1 | Advanced Thermostats..... | 165 |
| 3.4.2 | Advanced Wood Heating – Central Pellet Systems | 172 |
| 3.4.3 | Advanced Wood Heating – Pellet Stoves | 177 |
| 3.4.4 | Air Source Heat Pump – Ducted, Full Displacement | 182 |
| 3.4.5 | Air Source Heat Pump – Ducted, Partial Displacement | 188 |
| 3.4.6 | Air Source Heat Pump – Ductless, Full Displacement..... | 194 |
| 3.4.7 | Air Source Heat Pump – Ductless, Partial Displacement..... | 200 |
| 3.4.8 | Air-to-Water Heat Pumps | 206 |
| 3.4.9 | ERV/HRV | 211 |
| 3.4.10 | Ground Source Heat Pump | 219 |
| 3.5 | <i>Miscellaneous</i> | 226 |
| 3.5.1 | Efficient and Electric Manufactured Homes | 226 |
| 3.5.2 | Heat Pump Pool Water Heater | 230 |
| 4. | Fuel Measures | 235 |
| 4.1 | <i>Liquid and Gaseous Fuels</i> | 235 |
| 4.1.1 | Gaseous Hydrogen from Dedicated Renewables | 235 |
| 4.1.2 | Biomethane..... | 238 |
| 4.1.3 | Biodiesel..... | 241 |
| 4.1.4 | Renewable Diesel | 245 |
| 4.1.5 | Renewable Propane..... | 248 |

ACKNOWLEDGEMENTS

The TRM is a technical document developed by Opinion Dynamics pursuant to its statutorily defined role in Vermont Public Act 18 (Act 18) as “a third-party consultant responsible for developing clean heat measure characterizations and relevant assumptions, including CO₂e lifecycle emissions analyses.”¹ The TRM was greatly informed by direction from the Vermont Public Utility Commission, discussions in the Clean Heat Standard (CHS) Technical Advisory Group (TAG), comments from members of the public, and work conducted by other organizations, most notably the Efficiency Vermont TRM and Vermont Renewable Energy Standard Tier III TRM.

¹ 30 V.S.A. § 8126(c).

I. OVERVIEW

I.1 PURPOSE OF THE TRM

The purpose of the Vermont Clean Heat Standard Technical Reference Manual (CHS TRM) is to provide a consistent and transparent basis for calculating accurate and verifiable lifecycle carbon dioxide equivalent (CO₂e) emission reductions in Vermont’s thermal sector from the delivery of eligible clean heat measures to existing or new end-use customer locations into or in Vermont.

I.1.1 APPLYING THE CHS TRM

The CHS TRM is intended to be used by parties to minimize disagreement and misunderstanding in the implementation and verification of CHS activities. Consistent with TRMs developed for energy efficiency programs throughout Vermont and the United States, the CHS TRM is a reference document that provides two general categories of information:

- General information to be used to calculate CO₂e reductions throughout the CHS (e.g. background information, lifecycle emissions by fuel pathways, transmission and distribution losses, and the mix of fuel types used throughout Vermont for various enduses)
- Prescriptive measure characterizations for a specific subset of CHS measures that are deemed to be appropriate for such characterization

When described within the CHS TRM, parties implementing CHS measures should be bound by the assumptions and approaches laid out within the CHS TRM except in extraordinary circumstances. However, energy technologies and markets are highly dynamic, and the CHS TRM should not be viewed as an exhaustive list of CHS measures. For example, the CHS TRM does not include measures within three measure areas defined in Act 18: (4) Utility-controlled electric water heaters, (8) noncombustion or renewable energy-based district heating services, and (12) line extensions that connect facilities with thermal loads to the grid. Therefore, parties implementing CHS measures are free to propose and implement additional CHS measures (“custom measures”) that are not characterized in the CHS TRM, subject to further verification. Wherever possible, implementation of custom measures should consider information presented in the CHS TRM in the development and implementation of said measures.

The process of implementing custom measures and guidance for doing so is described further in Section 1.4.

I.1.2 DEEMED SAVINGS

I.2 GLOSSARY

Unless otherwise specified, all definitions are from or lightly adapted from 30 V.S.A. § 8123.

- **Advanced wood heating²:** An EPA-certified space heating technology that burns wood pellets with 50% more efficiency than older models and meets or exceeds the fine particulate emission standard of 0.08 lbs PM_{2.5}/MMBTU.
- **Carbon intensity value:** The amount of lifecycle greenhouse gas emissions per unit of energy of fuel expressed in grams of carbon dioxide equivalent per megajoule (gCO₂e/MJ).

² Additional definition not from 30 V.S.A. § 8123.

- **Clean heat credit:** A tradeable, nontangible commodity that represents the amount of greenhouse gas reduction attributable to a clean heat measure.
- **Clean heat measure:** Fuel delivered and technologies installed to end-use customers in Vermont that reduce greenhouse gas emissions from the thermal sector. Clean heat measures shall not include switching from one fossil fuel use to another fossil fuel use.
- **Commission:** The Vermont Public Utility Commission.
- **Customer with low income:** A customer with a household income of up to 60 percent of the area or statewide median income, whichever is greater, as published annually by the U.S. Department of Housing and Urban Development or a customer who qualifies for a government-sponsored, low-income energy subsidy.
- **Customer with moderate income:** A customer with a household income between 60 percent and 120 percent of the area or statewide median income, whichever is greater, as published annually by the U.S. Department of Housing and Urban Development.
- **Default delivery agent:** An entity designated by the Commission to provide services that generate clean heat measures.
- **Energy burden:** The annual spending on thermal energy as a percentage of household income.
- **Entity:** Any individual, trustee, agency, partnership, association, corporation, company, municipality, political subdivision, or any other form of organization.
- **Feedstock:**³ Materials used directly in manufacturing processes and transformed into an intermediate or finished material.⁴ For biofuels, a material input to fuel production such as an agricultural or waste product.
- **Firewood:**⁵ Untreated wood processed for residential, recreational, or commercial use in any wood-burning appliance or fireplace, either indoor or outdoor, that is cut to a length less than 48 inches, either split or unsplit. Does not include wood chips, wood pellets, pulpwood, logs 48 inches or more in length, or other wood sold or transported for manufacturing purposes.
- **Fuel pathway:** A detailed description of all stages of fuel production and use for any particular fuel, including feedstock generation or extraction, production, transportation, distribution, and combustion of the fuel by the consumer. The fuel pathway is used in the calculation of the carbon intensity value and lifecycle greenhouse gas emissions of each fuel.
- **Heating fuel:** Fossil-based heating fuel, including oil, propane, natural gas, coal, and kerosene.
- **Obligated party:**
 - A regulated natural gas utility serving customers in Vermont.
 - For other heating fuels, the entity that imports heating fuel for ultimate consumption within the State, or the entity that produces, refines, manufactures, or compounds heating fuel within the State for ultimate consumption within the State. For the purpose of this section, the entity that imports heating fuel is the entity that has ownership title to the heating fuel at the time it is brought into Vermont.
- **Thermal sector:** Defined as the “Residential, Commercial and Industrial Fuel Use” sector as used in the Vermont Greenhouse Gas Emissions Inventory and Forecast; does not include nonroad diesel or any other transportation or other fuel use categorized elsewhere in the Vermont Greenhouse Gas Emissions Inventory and Forecast.

³ Additional definition not from 30 V.S.A. § 8123.

⁴ U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Industrial Efficiency & Decarbonization Office. Accessed at: <https://www.energy.gov/eere/iedo/low-carbon-feedstocks-basics>

⁵ Definition sourced from 10 V.S.A. § 2681(a)(3).

I.3 TRM ASSUMPTIONS

As outlined in the acknowledgements, the CHS TRM is a technical document developed by Opinion Dynamics pursuant to its statutorily defined role in Act 18 as “a third-party consultant responsible for developing clean heat measure characterizations and relevant assumptions, including CO₂e lifecycle emissions analyses.”⁶ As such, the information in the TRM is that which Opinion Dynamics recommends be applied to the CHS, informed by direction from the Vermont Public Utility Commission, discussions in the Clean Heat Standard (CHS) Technical Advisory Group (TAG), comments from members of the public, and work conducted by other organizations, most notably the Efficiency Vermont TRM and Vermont Renewable Energy Standard Tier III TRM.

Wherever possible, we used recent, Vermont-specific information to develop the assumptions and recommendations in this TRM.

I.3.1 DOCUMENTATION OF SOURCES

In addition to the information contained within this document, the source information cited throughout the TRM underlying the measures presented here is available for review. At this time, this information is currently located on an Opinion Dynamics ShareFile website, which can be shared with any of those interested.

I.3.2 LIFECYCLE EMISSIONS SCHEDULE

INTRODUCTION

Act 18 established the Vermont CHS and places obligations on various Vermont stakeholders and agencies to develop the CHS. As part of Act 18, the Vermont Public Utility Commission (“the Commission”) is required to

“establish a schedule of lifecycle emissions rates for heating fuels and any fuel that is used in a clean heat measure, including electricity, or is itself a clean heat measure, including biofuels.”⁷

The lifecycle emissions rates schedule is to be combined with the measure characterizations included in this TRM to estimate carbon dioxide equivalent (CO₂e) reductions resulting from Vermont CHS measure. Measure characterizations are used to estimate changes in use of heating fuels and the lifecycle emissions rate schedule is used to estimate the total lifecycle CO₂e reduction associated with that change in fuels.

Act 18 provides explicit requirements for the development of the schedule:

“The schedule shall be based on transparent, verifiable, and accurate emissions accounting adapting the Argonne National Laboratory GREET Model, Intergovernmental Panel on Climate Change (IPCC) modeling, or an alternative of comparable analytical rigor to fit the Vermont thermal sector context, and the requirements of 10 V.S.A. § 578(a)(2) and (3).”⁸

“For each fuel pathway, the schedule shall account for greenhouse gas emissions from biogenic and geologic sources, including fugitive emissions and loss of stored carbon. In determining the baseline emission rates for clean heat measures that are fuels, emissions baselines shall fully account for methane emissions reductions or captures already occurring, or expected to occur, for each fuel

⁶ 30 V.S.A. § 8126(c).

⁷ 30 V.S.A. § 8127(g)(1).

⁸ 30 V.S.A. § 8127(g)(1).

pathway as a result of local, State, or federal legal requirements that have been enacted or adopted that reduce greenhouse gas emissions.”⁹

Opinion Dynamics developed a schedule consistent with these requirements, which is presented later in this section. We used different resources to estimate emissions rates by lifecycle phase (i.e., upstream and combustion).¹⁰ Broadly speaking, we relied upon Argonne National Laboratory’s Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) model¹¹ to estimate upstream emissions and the U.S. EPA Emission Factors Hub to estimate combustion emissions.¹² This information was supplemented for certain fuels with information from the Vermont Energy Sector Life Cycle Assessment report published by the Vermont Agency of Natural Resources,¹³ information from the Vermont Greenhouse Gas Emissions Inventory and Forecast,¹⁴ and information from an analysis conducted by Sustainable Energy Advantage on behalf of the Vermont Department of Public Service.¹⁵

The lifecycle emissions rate schedule is presented in Table 1 below. For further detail, including the disaggregation of lifecycle emissions rates into combustion and upstream emissions rates, please refer to the Excel workbook provided with this TRM.

⁹ 30 V.S.A. § 8127(g)(2).

¹⁰ Upstream emissions, also referred to as embodied carbon, include GHG emissions directly associated with fuel production, such as resource extraction and fuel upgrading. We exclude emissions from extraneous activities, such as manufacturing of equipment used in transportation of fuels.

¹¹ Argonne National Laboratory. (2024). The Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model (2023 rev1). Accessed at: <https://greet.anl.gov/>

¹² U.S. Environmental Protection Agency (2024). 2024 GHG Emissions Factors Hub. Accessed at: <https://www.epa.gov/climateleadership/ghg-emission-factors-hub>

¹³ Eastern Research Group, Inc. (2024). Vermont Energy Sector Life Cycle Assessment. Prepared for the VT Agency of Natural Resources. April 30, 2024.

¹⁴ Vermont Agency of Natural Resources (2024). Vermont Greenhouse Gas Emissions Inventory and Forecast: Methodologies. Accessed at: https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/1990-2021_GHG_Inventory_Uploads/Methodology_Vermont_Greenhouse_Gas_Emissions_Inventory_1990-2021_Final.pdf

¹⁵ Sustainable Energy Advantage, LLC. (2023). Technical Analysis of a 100% Renewable or Clean Energy Standard: Final Results. November 27, 2023. Accessed at:

<https://publicservice.vermont.gov/sites/dps/files/documents/VT%20RES%20Technical%20Analysis%20Final%20Report%2011.27.23.pdf>

Table 1. Lifecycle Emissions Rate Schedule

| Fuel | Lifecycle Average Emissions Rate (gCO ₂ e/MJ) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--|--|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 |
| Grid Electricity | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Grid electricity ^a | 37.8 | 37.8 | 37.8 | 35.1 | 32.5 | 29.9 | 27.3 | 24.6 | 22.0 | 19.4 | 16.8 | 14.1 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 |
| Liquid and Gaseous Fuels | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Natural gas | 63.7 | 63.7 | 63.7 | 63.7 | 63.7 | 63.7 | 63.7 | 63.7 | 63.7 | 63.7 | 63.7 | 63.7 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 |
| Fuel oil #2 | 83.4 | 83.4 | 83.5 | 83.5 | 83.5 | 83.5 | 83.5 | 82.9 | 82.9 | 82.9 | 82.9 | 82.9 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.7 |
| Propane | 73.6 | 73.6 | 73.6 | 73.6 | 73.6 | 73.6 | 73.6 | 73.2 | 73.2 | 73.2 | 73.2 | 73.2 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 | 73.1 |
| Kerosene | 83.6 | 83.6 | 83.7 | 83.7 | 83.7 | 83.7 | 83.7 | 83.1 | 83.1 | 83.1 | 83.1 | 83.1 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 83.0 | 82.9 |
| Coal | 94.6 | 94.6 | 94.5 | 94.5 | 94.5 | 94.5 | 94.5 | 94.5 | 94.5 | 94.5 | 94.5 | 94.5 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 | 94.4 |
| Hydrogen (gaseous) from SMR | 94.5 | 94.5 | 92.7 | 92.7 | 92.7 | 92.7 | 92.7 | 88.1 | 88.1 | 88.1 | 88.1 | 88.1 | 87.2 | 87.2 | 87.2 | 87.2 | 87.2 | 87.0 | 87.0 | 87.0 | 87.0 | 87.0 | 86.7 | 86.7 | 86.7 | 86.7 | 86.7 | 86.1 |
| Hydrogen (gaseous) from dedicated renewables | 14.2 | 14.2 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 6.9 | 6.9 | 6.9 | 6.9 | 6.9 | 6.3 |
| Biomethane from animal waste | -63.3 | -63.3 | -65.4 | -65.4 | -65.4 | -65.4 | -65.4 | -71.0 | -71.0 | -71.0 | -71.0 | -71.0 | -72.0 | -72.0 | -72.0 | -72.0 | -72.0 | -72.3 | -72.3 | -72.3 | -72.3 | -72.3 | -72.6 | -72.6 | -72.6 | -72.6 | -72.6 | -73.1 |
| Biomethane from landfill gas | 6.8 | 6.8 | 5.9 | 5.9 | 5.9 | 5.9 | 5.9 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.3 |
| Biomethane from fats, oils, and greases | 28.1 | 28.1 | 25.3 | 25.3 | 25.3 | 25.3 | 25.3 | 18.3 | 18.3 | 18.3 | 18.3 | 18.3 | 17.1 | 17.1 | 17.1 | 17.1 | 17.1 | 16.7 | 16.7 | 16.7 | 16.7 | 16.7 | 16.3 | 16.3 | 16.3 | 16.3 | 16.3 | 15.7 |
| Biomethane from wastewater | -9.7 | -9.7 | -11.2 | -11.2 | -11.2 | -11.2 | -11.2 | -15.3 | -15.3 | -15.3 | -15.3 | -15.3 | -16.0 | -16.0 | -16.0 | -16.0 | -16.0 | -16.2 | -16.2 | -16.2 | -16.2 | -16.2 | -16.5 | -16.5 | -16.5 | -16.5 | -16.5 | -16.8 |
| Biodiesel from soybeans | 27.4 | 27.4 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 25.2 | 25.2 | 25.2 | 25.2 | 25.2 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 24.9 | 24.9 | 24.9 | 24.9 | 24.9 | 24.9 | 24.9 | 24.9 | 24.9 | 24.9 | 24.7 |
| Biodiesel from canola | 35.0 | 35.0 | 34.5 | 34.5 | 34.5 | 34.5 | 34.5 | 33.5 | 33.5 | 33.5 | 33.5 | 33.5 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.3 | 33.2 | 33.2 | 33.2 | 33.2 | 33.2 | 33.1 |
| Biodiesel from corn | 40.0 | 40.0 | 38.4 | 38.4 | 38.4 | 38.4 | 38.4 | 36.0 | 36.0 | 36.0 | 36.0 | 36.0 | 35.6 | 35.6 | 35.6 | 35.6 | 35.6 | 35.5 | 35.5 | 35.5 | 35.5 | 35.5 | 35.4 | 35.4 | 35.4 | 35.4 | 35.4 | 35.2 |
| Biodiesel from used cooking oil | 13.9 | 13.9 | 13.5 | 13.5 | 13.5 | 13.5 | 13.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.2 | 12.1 | 12.1 | 12.1 | 12.1 | 12.1 | 11.9 |
| Renewable diesel from soybeans | 30.7 | 30.7 | 29.9 | 29.9 | 29.9 | 29.9 | 29.9 | 28.4 | 28.4 | 28.4 | 28.4 | 28.4 | 28.1 | 28.1 | 28.1 | 28.1 | 28.1 | 28.0 | 28.0 | 28.0 | 28.0 | 28.0 | 28.0 | 28.0 | 28.0 | 28.0 | 28.0 | 27.8 |
| Renewable diesel from canola | 40.4 | 40.4 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 38.8 | 38.8 | 38.8 | 38.8 | 38.8 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 | 38.3 |
| Renewable diesel from corn | 44.4 | 44.4 | 42.8 | 42.8 | 42.8 | 42.8 | 42.8 | 40.3 | 40.3 | 40.3 | 40.3 | 40.3 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 39.9 | 39.9 | 39.9 | 39.9 | 39.9 | 39.8 | 39.8 | 39.8 | 39.8 | 39.8 | 39.6 |
| Renewable diesel from used cooking oil | 17.7 | 17.7 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 | 15.7 | 15.7 | 15.7 | 15.7 | 15.7 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.5 | 15.5 | 15.5 | 15.5 | 15.5 | 15.4 |
| Wood Fuels | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Wood chips | 2.8 | 2.8 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.3 |
| Wood pellets | 27.5 | 27.5 | 26.8 | 26.8 | 26.8 | 26.8 | 26.8 | 24.9 | 24.9 | 24.9 | 24.9 | 24.9 | 24.6 | 24.6 | 24.6 | 24.6 | 24.6 | 24.5 | 24.5 | 24.5 | 24.5 | 24.5 | 24.4 | 24.4 | 24.4 | 24.4 | 24.4 | 24.2 |
| Firewood, commercial | 70.2 | 70.2 | 70.1 | 70.1 | 70.1 | 70.1 | 70.1 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 69.9 |

Note: Emissions rates are inclusive of both combustion and upstream emissions. For further information, please see the Excel workbook provided with this memo.

^a Values are based on resource-weighted contributions per generation resource type, e.g., hydroelectric, natural gas, and wind.

METHODOLOGY

The emissions rate schedule presented in this document characterizes carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) emissions for fuels. Emissions of CH₄ and N₂O were converted to CO₂e using 100-year global warming potential (GWP) factors produced by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, 2014 (AR5).¹⁶ Emissions are converted to emissions rates based on the volume of energy that is generated by an electricity generating unit (EGU) or delivered to a delivery agent (e.g. VGS or a fuel wholesaler); e.g., gram of CO₂e per megajoule (CO₂e/MJ) of electricity generated.

Our emissions rate schedule, in line with the requirements of Act 18, reflects both **upstream** and **combustion** emissions of the greenhouse gases (GHGs) detailed above.

- **Upstream** emissions reflect the volume of GHG releases resulting from activities occurring during the upstream lifecycle phase of a fuel, such as resource extraction, feedstock processing, fuel production, and transportation to distributors or electricity generation units (EGU). Upstream emissions also include the avoided emissions associated with the counterfactual scenario.
- **Combustion** emissions reflect the volume of GHG emissions that are released at the time of combustion of a fuel, such as an EGU burning coal to generate electricity or from combustion of fossil fuels in forced-air furnaces.

Summing these emissions rates produces a lifecycle emissions rate for the fuel being studied.

The following sections detail the methodology we used in estimating upstream and combustion emissions rates. Grid electricity, liquid/gaseous fuels, and wood fuels use somewhat different methodologies. Underlying analytical files used to develop the emissions rates are included on the Opinion Dynamics ShareFile.

Emissions Rate for Grid Electricity

We developed a Vermont-specific lifecycle average emissions rate for grid electricity. To develop this emissions rate, we took the following steps:

1. We first developed a projected resource mix by year for the Vermont electric grid from 2025 through 2050.
 - a. This resource mix assumes a starting resource mix as reflected in the Vermont Energy Sector Life Cycle Assessment report.¹⁷
 - b. This resource mix assumes that by 2035, Vermont's resource mix will be 100% renewable per the Vermont Renewable Energy Standard (RES).¹⁸ To forecast the mix of the renewable resources that will make up this 100% renewable grid in 2035, we used an analysis conducted by Sustainable Energy Advantage on behalf of the Vermont Department of Public Service.¹⁹
 - c. We then interpolated the starting resource mix and the 2035 100% renewability benchmark to develop a year-over-year projection of the Vermont electric grid resource mix.
 - d. After 2035, we hold the projected resource mix constant.
2. We then apply emissions rates to the resource mix to estimate combined grid electricity emissions.
 - a. Combustion emissions rates come from the U.S. EPA Emission Factors Hub, corrected for average EGU combustion efficiencies using average plant efficiency factors.

¹⁶ CH₄ emissions have a GWP of 28 and N₂O emissions have a GWP of 265.

¹⁷ Eastern Research Group, Inc. (2024). Vermont Energy Sector Life Cycle Assessment. Prepared for the VT Agency of Natural Resources. April 30, 2024.

¹⁸ Our analysis assumes that 100% renewable means truly 100% renewable including all marginal electricity supply.

¹⁹ Sustainable Energy Advantage, LLC. (2023). Technical Analysis of a 100% Renewable or Clean Energy Standard: Final Results. November 27, 2023. Accessed at:

<https://publicservice.vermont.gov/sites/dps/files/documents/VT%20RES%20Technical%20Analysis%20Final%20Report%2011.27.23.pdf>

- b. Upstream emissions rates come from Opinion Dynamics analysis using GREET1 2023rev1, following the same approach as used in the Vermont Energy Sector Life Cycle Assessment report.²⁰

This approach produces a Vermont-specific average grid electricity lifecycle emissions rate that reflects Vermont policy. We applied the annual average electric resource mix instead of the long-run marginal resource mix for several reasons; most notably limited data and an inability to combine existing datasets due to differences in geography (e.g., New England vs. Vermont) and grid perspectives (e.g., long-run marginal vs. average mixes) while reflecting the Vermont RES. We deemed approaches that attempted to estimate a marginal emissions rate while reflecting these characteristics to be internally inconsistent.

Transmission and Distribution Losses

The emissions rate for grid electricity presented in this memo does not account for electric transmission and distribution losses. These losses are accounted for in the CHS to accurately reflect emissions changes associated with measures that use grid electricity. A transmission and distribution line loss factor, detailed in Section 1.3.3, is applied in the decarbonization measure calculations for each measure using grid electricity to account for these losses.

Emissions Rates for Liquid and Gaseous Fuels

Upstream emissions for liquid and gaseous fuels were developed using GREET1 2023rev1, following a similar analytical framework as used in the Vermont Energy Sector Life Cycle Assessment report.²¹

Combustion emissions were estimated using combustion emissions rates for CO₂, CH₄, and N₂O from the U.S. EPA Emission Factors Hub.²² Note that combustion of hydrogen does not produce CO₂, CH₄, or N₂O and therefore combustion emissions for hydrogen were set to zero.

Treatment of Biogenic Carbon for Liquid and Gaseous Fuels

For biofuels (biomethane, biodiesel, and renewable diesel), we consider CO₂ released in combustion to be a part of the biogenic carbon cycle; when biogenic carbon is emitted through combustion of these fuels, we assume it is re-sequestered by near-term regrowth of the biological material that initially led to the development of these fuels. We did account for CH₄ and N₂O released by combustion of these fuels in the reported emissions rates.

Counterfactual Emissions Scenarios

Our emissions analysis incorporates counterfactual scenarios for all biomethane fuel pathways and for biodiesel and renewable diesel fuels where used cooking oil is the feedstock. For the other biodiesel and renewable diesel fuels, no counterfactual scenarios are considered, as these fuels are assumed to be grown on dedicated land for explicit use in the energy sector.

Biomethane counterfactual scenarios vary by pathway. Biomethane produced from landfill gas assumes collection of landfill gas with 100% of the gas flared. Biomethane production occurs at landfills where biogas collection is present supporting the assumption that in lieu of biomethane production, the biogas would be flared rather than released. Therefore, the counterfactual scenario avoids emissions resulting from biogas flaring. Biomethane produced from fats, oils, and greases assume that these feedstocks would be landfilled otherwise and subsequently applies the landfill gas counterfactual scenario described above.

²⁰ Eastern Research Group, Inc. (2024). Vermont Energy Sector Life Cycle Assessment. Prepared for the VT Agency of Natural Resources. April 30, 2024.

²¹ Ibid.

²² U.S. Environmental Protection Agency (2024). 2024 GHG Emissions Factors Hub. Accessed at: <https://www.epa.gov/climateleadership/ghg-emission-factors-hub>

In wastewater treatment plants, anaerobic digestion produces supernatant, digestate, and biogas, which is collected for biomethane production. The counterfactual scenario assumes a blend of biogas handling methods with 44% flared, 55% combusted in a boiler for process heat utilized at the plant, and 1% released through leakage. The counterfactual scenario also includes increased grid electricity to operate the anaerobic digester and centrifuge for the digestate, as well as methane leakage from the supernatant, sludge holding tanks, centrifuges, storage tanks, and leakage during biogas collection. Therefore, the counterfactual scenario avoids increased methane leakage and combustion emissions.

The counterfactual scenario for biomethane from animal manure assumes avoidance of traditional animal waste treatment, which may involve storage in deep pits, anaerobic lagoons, or as solids, or it may be spread over pastures. Animal waste is comprised of 7.5% biogenic CO₂ in the biogas, 85% solid waste residue, 7.5% recoverable methane, of which 60% is flared and 40% is non-combusted, and a <0.1% unrecoverable methane. The counterfactual scenario avoids emissions related to flaring of biogas and release of methane and nitrous oxide.

Biodiesel produced from used cooking oils assume that these feedstocks would be landfilled otherwise and subsequently applies the landfill gas counterfactual scenario described above.

Transmission and Distribution Losses and Additional Emissions

REET accounts for transmission and distribution losses from the fuel producer to the distributor, and those losses are therefore incorporated into our emissions rates for liquid and gaseous fuels. Our emissions rates for liquid and gaseous fuels do not, however, account for any additional emissions or losses that are incurred from distribution of fuels from the distributor to the end-user (such as natural gas distribution system losses or delivery of liquid fuels to a customer from a distribution center). Natural gas distribution losses and delivered fuel emissions are accounted for in the CHS through application of the factors presented in Section 1.3.3. The carbon intensity adder values for delivered fuels are based on general assumptions, notably the delivery of a full truck load of fuel, with the resulting emissions normalized to the energy content of the delivered fuel.

Lifecycle Emissions from Renewable Propane

While lifecycle carbon intensity values presented in Table 1 for most fuels were developed through lifecycle analysis conducted by Opinion Dynamics, public tools for lifecycle analysis that meet the requirements of 30 V.S.A. § 8127(g)²³ were not available to Opinion Dynamics for renewable propane. Therefore, we did not conduct a detailed lifecycle analysis for renewable propane. However, fossil propane is currently used as a primary heating fuel for a significant share of Vermont's existing buildings and renewable propane is currently commercially available. Given this, TAG members expressed their support for the inclusion of renewable propane in the CHS TRM.

In lieu of a rigorous lifecycle analysis that meets the requirements of 30 V.S.A. § 8127(g) but in service of TAG requests, we worked to develop a placeholder carbon intensity value for renewable propane through review and analysis of the active pathways for renewable propane recorded in the California Low Carbon Fuel Standard (LCFS) database.²⁴ As of October 3, 2024, there were 17 active pathways for renewable propane recorded in the LCFS database. The active pathways describe production of renewable propane from a variety of organic waste feedstocks, including animal fat, corn oil, soybean oil, and used cooking oil. We calculated the average carbon intensity value across all 17 pathways, which yields a value of 33.91 gCO₂e/MJ. We conducted various sensitivity analyses, including 1) limiting the analyzed pathways to North American-sourced feedstocks only (to be consistent with recommendations made elsewhere in this

²³ "...shall be based on transparent, verifiable, and accurate emissions accounting adapting the Argonne National Laboratory REET Model, Intergovernmental Panel on Climate Change (IPCC) modeling, or an alternative of comparable analytical rigor to fit the Vermont thermal sector context, and the requirements of 10 V.S.A. § 578(a)(2) and (3)"

²⁴ LCFS Pathway Certified Carbon Intensities, updated as of October 3, 2024. Accessed at: <https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities>. Renewable propane pathways modify the LCFS Simplified REET Biodiesel calculator.

TRM) and 2) including the nine retired pathways memorialized in the database, and saw only slight changes to the average.

In order to most transparently memorialize a carbon intensity value for renewable propane, we selected a representative pathway from the LCFS. Pathway B042122 characterizes the production of renewable propane in Louisiana from North American sourced corn oil. The LCFS database certifies the pathway for this fuel as having a carbon intensity of 33.0 gCO₂e/MJ, which became our recommended placeholder value for renewable propane in the CHS until more transparent analytical tools for renewable propane become available.

It is important to note that as a result of using a pathway carbon intensity value from LCFS, certain features of the carbon intensity value for renewable propane differ from carbon intensity values provided for other fuels. In particular, the carbon intensity value for renewable propane presented here is not time-variant and does not account for changing carbon intensities of the production process. The carbon intensity value represents only the production pathway at a single facility and is therefore not reflective of the national production pathways for renewable propane as is done for all other liquid and gaseous fuels in the CHS. In addition, while the carbon intensity value for renewable propane presented here does account for upstream emissions, the presented value cannot be easily split into upstream vs. combustion emissions, which may present challenges in reconciling any CHS credits awarded for renewable propane with the Vermont Greenhouse Gas Inventory.

The Vermont Public Utility Commission reviewed this analysis and determined that this placeholder value of 33.0 gCO₂e/MJ does not meet the statutory requirements presented in 30 V.S.A. § 8127(g)(1), and therefore cannot be used in the determination of clean heat credits.

Emissions Rates for Wood Fuels

Upstream emissions for wood fuels were developed using GREET1 2023rev1, following a similar analytical framework as used in the Vermont Energy Sector Life Cycle Assessment report.²⁵ Feedstocks differ for the three wood fuels. Wood chips and wood pellets are produced from waste by-products, such as scraps and residues occurring at lumber mills. As a result, upstream emissions associated with forest management, harvesting, and lumber milling are zero. However, some upstream emissions are still associated with these fuels, such as production of wood pellets from waste residues and transport of finished fuels to distributors.

Combustion emissions were estimated using combustion emissions rates for CO₂, CH₄, and N₂O from the U.S. EPA Emission Factors Hub.²⁶ A GWP_{bio} factor is applied to combustion emissions, discussed in the next section.

Treatment of Biogenic Carbon for Wood Fuels

For wood fuels, we consider CO₂ released in combustion to be part of a longer biogenic carbon cycle than biofuels, in which it takes significant time for the regrowth of new trees to fully sequester the biogenic carbon emitted during combustion. In line with an alternative approach presented in the Vermont Greenhouse Gas Emissions Inventory and Forecast,²⁷ we apply a GWP_{bio} factor to CO₂ combustion emissions from wood fuels to account for the regrowth period of the fuel. For firewood, we apply a GWP_{bio} factor of 0.75 in our analysis. For wood chips and wood pellets, a GWP_{bio} factor of 0 is applied because these fuels are produced from waste by-products and the burden of upstream activities

²⁵ Eastern Research Group, Inc. (2024). Vermont Energy Sector Life Cycle Assessment. Prepared for the VT Agency of Natural Resources. April 30, 2024.

²⁶ U.S. Environmental Protection Agency (2024). 2024 GHG Emissions Factors Hub. Accessed at: <https://www.epa.gov/climateleadership/ghg-emission-factors-hub>

²⁷ Vermont Agency of Natural Resources (2024). Vermont Greenhouse Gas Emissions Inventory and Forecast: Methodologies. Accessed at: https://outside.vermont.gov/agency/anr/climatecouncil/Shared%20Documents/1990-2021_GHG_Inventory_Uploads/Methodology_Vermont_Greenhouse_Gas_Emissions_Inventory_1990-2021_Final.pdf

predominately fall on the purpose of harvest, e.g., lumber. We did not apply a factor to CH₄ and N₂O emissions released by combustion of wood fuels in the reported emissions rates.

Treatment of Land Use Changes for Wood Fuels

For wood fuels, our emissions analysis assumes that there is no change in land use associated with the wood fuel that needs to be quantified in our emissions rates.

As described in the Vermont Energy Sector Life Cycle Assessment report, GREET1 2023rev1 models energy and emissions associated with short rotation woody crops with the embedded assumption that these crops are grown for the dedicated use in the energy sector. This assumption is not consistent with typical forestry management strategies in Vermont. Nevertheless, a pathway for accounting for land use changes in Vermont is not evident to us. In addition, the decision to not account for land use change is consistent with the handling of land use change for biofuels described above. Being consistent in this accounting supports comparative results across biofuels. The implications of land use change in the forestry sector as a result of the energy sector could be further explored in future CHS updates.

Allocation Methods for Dealing with Co-Products

When conducting lifecycle analysis, analytical choices must be made around how to deal with co-products. GREET includes a default allocation method for each fuel pathway analyzed. The default allocation methods utilized include process-level/displacement, marginal, energy-based, mass-based, and market value-based. Each allocation method has strengths and weaknesses in use for the CHS, but because these methods are not interchangeable, we chose to move towards an energy-based allocation method for all fuels for consistency. This was chosen for several reasons. First, we are not utilizing GREET for the purposes for which it was originally designed (fuel usage in transportation). Second, the emissions schedule is intended to reflect national or regional production pathways and counterfactual scenarios and is not attempting to model specific facility-level production processes. Third, the market value for some fuels is still emerging, especially as a heating fuel in buildings and industrial processes. For these reasons, we chose to apply the energy-based allocation method, which is easily understood and universally applicable to fuels as the energy content of fuels and feedstocks are well defined and generally static. As the market emerges for clean heating fuels in Vermont, and nationally, a market-based allocation method may be better suited for attributing emissions to co-products.

Earlier versions of our lifecycle analysis utilized the GREET default allocations. For transparency, Table 2 summarizes the default allocation methods for fuel pathways that were employing an allocation method other than energy-based in earlier iterations of the emissions schedule.

Table 2. Default Allocation Method and Affected Processes

| Fuel Emissions Schedule Name | GREET Default Allocation Method | Affected Processes |
|---------------------------------|---------------------------------------|--|
| Biodiesel from soybeans | Process Level Allocation/Displacement | System-wide |
| Biodiesel from canola | Process Level Allocation/Displacement | System-wide |
| | Market Value | Fuel Production |
| Biodiesel from corn | Market Value | Oil Extraction and Fuel Production |
| Biodiesel from used cooking oil | Market Value | Fuel Production |
| Renewable diesel from soybeans | Process Level Allocation/Displacement | System-wide |
| Renewable diesel from canola | Process Level Allocation/Displacement | System-wide |
| Hydrogen from SMR | Displacement method | System-wide |
| Wood chips ^a | Process-level economic allocation | Lumber mill operations (sawing and planning) |

| Fuel Emissions Schedule Name | GREET Default Allocation Method | Affected Processes |
|------------------------------|-----------------------------------|--|
| Wood pellets ^a | Process-level economic allocation | Lumber mill operations (sawing and planning) |

^a The revised allocation method for these fuels is “Residue - does not share energy use at lumber mills” as they are considered waste by-products. The forest harvest process already assumed a waste by-product allocation in the first iteration of the emissions schedule.

1.3.3 TRANSMISSION AND DISTRIBUTION LOSSES AND CARBON INTENSITY ADDERS

The upstream lifecycle carbon intensities modeled in GREET account for emissions generated from fuel production and transport of the finished fuel to a distributor, such as a power plant or liquid fuels retailer. The combustion carbon intensities account for the emissions that are generated at the time of fuel combustion. These values leave a small, but notable gap, in the lifecycle carbon emissions accounting for fuels: transmission and distribution of a finished fuel to the end user. Carbon intensity adders for delivery of fuels to end user and transmission and distribution loss factors are required to calculate full lifecycle carbon reductions from many measures in this document. Table 3 presents those values for reference.

Table 3. Transmission and Distribution Losses and Carbon Intensity Adders

| Fuel Emissions Schedule Name | Carbon Intensity Adder (CI) [gCO _{2e} /MJ] | Transmission and Distribution Losses (%) | Source |
|------------------------------|---|--|--|
| Natural gas | N/A | 1.4% | GREET1 2023rev assumption on natural gas pipeline leakage rate |
| Grid electricity | N/A | 8.95% | Average of winter and summer average losses at peak hour presented in Table 77 of PUC Case No. 21-2436-PET |
| Fuel oil #2 | 0.2149 | N/A | Analysis of tailpipe emissions resulting from delivery of a 3,000 gallons of fuel by a class 5 diesel truck traveling 90 miles roundtrip. Assumptions are based on the best available information at the time of the analysis. |
| Propane | 0.3276 | N/A | |
| Kerosene | 0.2221 | N/A | |
| Wood chips | 1.9568 | N/A | Analysis of tailpipe emissions resulting from delivery of one pallet of wood fuel by a class 5 diesel truck traveling 34 miles roundtrip. Assumptions are based on the best available information at the time of the analysis. |
| Wood pellets | 1.9568 | N/A | |
| Firewood, commercial | 0.7986 | N/A | |
| Wood, unspecified | 1.3777 | N/A | Average of firewood and wood chips or wood pellets, since wood chips are assumed used in the commercial sector and wood pellets are assumed used in the residential sector; firewood is assumed used in both sectors. |

1.4 CUSTOM MEASURES

As described in Section 1.1.1, the CHS TRM provides a specific set of “prescriptive” measure characterizations for measures that are suitable for such standardized characterization and for which information was available during the development of this TRM.

However, the exclusion of a measure characterization²⁸ does not mean such a measure is ineligible for the CHS. For example, the CHS TRM does not include measures within three measure areas statutorily defined in Act 18 as being eligible for the CHS: (4) Utility-controlled electric water heaters, (8) noncombustion or renewable energy-based district

²⁸ A measure characterization should be understood to be the exclusion of the measure itself, such as window heat pumps, or a delivery channel for said measure, such as green hydrogen distributed through the natural gas distribution system.

heating services, and (12) line extensions that connect facilities with thermal loads to the grid. These measures have been determined to be more appropriate to be analyzed through project-specific custom analysis.

In cases where measures an entity intends to pursue as CHS measures do not appear in the CHS TRM, that entity is free to use algorithms and/or input values that do not yet appear in the TRM, subject to later verification as part of the CHS measurement and verification process.

2. COMMERCIAL/INDUSTRIAL INSTALLED MEASURES

2.1 APPLIANCES

2.1.1 HEAT PUMP CLOTHES DRYERS

CHS Measure ID: CI_APPL_HPCD

Market Sector: Commercial/Industrial

End Use: Appliances

Applicable Building Types: Non-Residential, Multifamily Common Areas

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane

Decision/Action Type: MOP

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This characterization involves installing residential grade heat pump clothes dryers to replace conventional gas dryers in commercial settings and in multifamily common areas. Heat pump clothes dryers (HPCD) use efficient heat pump technology for heating the dryer air instead of conventional gas or electric heating elements. Hybrid heat pump dryers may also use this characterization. These products use a heat pump as the primary heating source, but also include a secondary gas or electric heating element that may be enabled to dry the clothes faster.

This characterization encompasses HPCDs installed in coin-operated laundromats, on-premise laundromats, and multifamily common areas. It can also be used for other settings if the number of drying cycles per year is collected. It includes indirect space heating and cooling impacts resulting from the measure. Clean heat credits are awarded based on direct impacts and indirect space heating impacts.

Baseline Conditions

The assumed baseline is a minimum efficiency natural gas or propane dryer.

Proposed Conditions

The proposed condition is a heat pump or hybrid heat pump clothes dryer.

ELIGIBILITY CRITERIA

The efficient dryer must be an ENERGY STAR-certified full heat pump or hybrid heat pump model. Both standard and compact-sized units are eligible in this characterization.

This characterization is intended for fuel switching scenarios. Electric dryers are not an eligible baseline technology.

DECARBONIZATION SUMMARY

Table 4 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- ENERGY STAR-certified standard-sized (≥ 4.4 ft³) dryer, heat pump or hybrid heat pump
- Central A/C presence is unknown/not collected
- Space heating fuel type is unknown/not collected

Table 4. Example C/I Heat Pump Clothes Dryer CO₂e Reductions

| Setting | ENERGY STAR Most Efficient? | Baseline Dryer Fuel | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|--------------------------|-----------------------------|---------------------|---|--|------------------|
| Coin-Operated Laundromat | No | Natural Gas | 9,616,392 | 9,549,910 | 9.62 |
| | | Propane | 11,066,863 | 11,000,381 | 11.07 |
| | Yes | Natural Gas | 9,821,371 | 9,787,569 | 9.82 |
| | | Propane | 11,271,842 | 11,238,040 | 11.27 |
| Multifamily Common Area | No | Natural Gas | 23,389,297 | 23,227,596 | 23.39 |
| | | Propane | 26,917,179 | 26,755,477 | 26.92 |
| | Yes | Natural Gas | 23,887,853 | 23,805,638 | 23.89 |
| | | Propane | 27,415,735 | 27,333,519 | 27.42 |
| On-Premise Laundromat | No | Natural Gas | 6,964,265 | 6,916,118 | 6.96 |
| | | Propane | 8,014,707 | 7,966,560 | 8.01 |
| | Yes | Natural Gas | 7,112,712 | 7,088,233 | 7.11 |
| | | Propane | 8,163,155 | 8,138,675 | 8.16 |

DECARBONIZATION AND ENERGY IMPACT ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}} + \Delta\text{CO}_2\text{e}_{\text{heat}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g] due to equipment replacement} = \text{CO}_2\text{e}_{\text{base dryer}} - \text{CO}_2\text{e}_{\text{hp dryer}}$$

$CO2e_{base\ dryer} = \text{Annual } CO2e \text{ emissions [g] from baseline dryer}$

Propane: $CO2e_{base\ dryer} = E_{base\ dryer} \times (CI_{LP} + CI'_{LP})$

Natural gas: $CO2e_{base\ dryer} = (E_{base\ dryer} \times CI_{NG}) / (1 - TDL_{NG})$

$E_{base\ dryer} = \text{Baseline dryer energy usage} = \text{Load} / CEF_{base} \times 3.6$

$CEF_{base} = \text{Minimum Combined Energy Factor (CEF) for vented gas dryer [lbs/kWh]} = 2.84.^1$

$CO2e_{hp\ dryer} = \text{Annual } CO2e \text{ emissions [g] from heat pump or hybrid dryer} = (E_{hp\ dryer} \times CI_{elec}) / (1 - TDL_{elec})$

$E_{hp\ dryer} = \text{Load} / CEF_{hp} \times 3.6$

$CEF_{hp} = \text{CEF of the heat pump dryer unit based on type and ENERGY STAR level.}^2$

Table 5. Heat Pump Clothes Dryer CEF by Type (CEF_{hp})

| Technology | Size | CEF_{hp} [lbs/kWh] | |
|--------------------------|---------------------|----------------------|----------------------------|
| | | ENERGY STAR | ENERGY STAR Most Efficient |
| Heat Pump | Standard | 4.30 | 9.13 |
| Heat Pump | Compact | 3.36 | 6.25 |
| Hybrid Heat Pump | Standard or Compact | 4.50 | 6.03 |
| Unknown (full or hybrid) | Standard | 4.47 | 8.17 |
| Unknown (full or hybrid) | Compact | 3.36 | 6.25 |

Annual clothes drying load

$\text{Load} = \text{Annual clothes drying load [lbs]} = \text{Weight} \times N_{cycles}$

$\text{Weight} = \text{Average clothes dryer load weight [lbs].}^3$

Table 6. Average Load Weight by Dryer Size

| Dryer Size | Average Weight [lbs] |
|--------------------------------------|----------------------|
| Standard ($\geq 4.4 \text{ ft}^3$) | 8.45 |
| Compact ($< 4.4 \text{ ft}^3$) | 3.00 |

¹ Illinois Technical Reference Manual. V12.0. Based on federal standards and adjusted to CEF-D2 (equivalent to as if tested under Appendix D2 as performed in the ENERGY STAR analysis. Units are lbs/kWh for gas and electric dryers.

² Based on ENERGY STAR certified products list downloaded on 8/5/2024, <https://www.energystar.gov/productfinder/product/certified-clothes-dryers/results>. See "HP clothes dryers analysis 2024-08-05.xlsx".

³ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 178, footnote 12

N_{cycles} = Number of dryer cycles per year based on setting.

Table 7. Assumed Number of Dryer Cycles Per Year

| Setting | N_{cycles} |
|---------------------------------------|--------------|
| Coin-Operated Laundromat ⁴ | 1,483 |
| Multifamily Common Area ⁵ | 3,607 |
| On-Premise Laundromat ⁶ | 1,074 |
| Other | Use actual |

Space Heating Impacts

If the primary space heating fuel is known:

$$\text{Oil: } \Delta CO2_{e_{heat}} = (\Delta E_{hl} \times (CI_{oil} + CI'_{oil})) / \eta_{ave,oil}$$

$$\text{Propane: } \Delta CO2_{e_{heat}} = (\Delta E_{hl} \times (CI_{LP} + CI'_{LP})) / \eta_{ave,LP}$$

$$\text{Natural Gas: } \Delta CO2_{e_{heat}} = ((\Delta E_{hl} \times CI_{NG}) / \eta_{ave,NG}) / (1 - TD_{LNG})$$

$$\text{Wood: } CO2_{e_{wood}} = (\Delta E_{hl} \times (CI_{wood} + CI'_{wood})) / \eta_{ave,wood}$$

If the primary space heating fuel is unknown:

$$\Delta CO2_{e_{heat}} = ((\%Oil \times \Delta E_{hl} \times (CI_{oil} + CI'_{oil})) / \eta_{ave,oil}) + ((\%LP \times \Delta E_{hl} \times (CI_{LP} + CI'_{LP})) / \eta_{ave,LP}) + ((\%NG \times \Delta E_{hl} \times CI_{NG}) / \eta_{ave,NG}) / (1 - TD_{LNG}) + ((\%Elec \times \Delta E_{hl} \times CI_{elec}) / \eta_{ave,elec}) / (1 - TD_{elec}) + ((\%Wood \times \Delta E_{hl} \times (CI_{wood} + CI'_{wood})) / \eta_{ave,wood})$$

$\%Oil$, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 8)⁷

$\eta_{ave,fuel}$ = Average heating efficiency for each fuel type [dimensionless] (see Table 8)⁸

⁴ Illinois Technical Reference Manual, V12.0, Modulating Commercial Gas Clothes Dryer. "From DOE's Federal Register Notices, Energy Conservation Program: Energy Conservation Standards for Commercial Clothes Dryers, Office of Energy Efficiency & Renewable Energy."

⁵ Ibid.

⁶ Illinois Technical Reference Manual, V12.0, Modulating Commercial Gas Clothes Dryer. "Average value for dryer cycles in healthcare facility, hotels, drycleaners and laundromats from tests conducted in Nicor Gas Emerging Technology Program's Commercial Dryer Modulation Retrofit Public Project Report."

⁷ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. "Other" fuel category removed.

⁸ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

Table 8. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | Fuel % | Average Heating Efficiency (η_{heat}) |
|--------------|--------|---|
| Fuel oil #2 | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural gas | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

Change in heating load:

$$\Delta E_{\text{hl}} = - (\text{WHHF} \times \% \text{Conditioned}) \times ((\text{HR}_{\text{base}} \times E_{\text{base dryer}}) - (\text{HR}_{\text{hp}} \times E_{\text{hp dryer}}))$$

WHHF = Portion of reduced waste heat that results in increased heating = 0.558.⁹

%Conditioned = Portion of buildings with dryer in conditioned space = 73%.¹⁰

Non-Thermal Sector CO₂e Impacts:

$$\Delta \text{CO}_2 e_{\text{cool}} = \text{Space cooling impacts [g]} = (\Delta E_{\text{cl}} \times \text{Cl}_{\text{elec}}) / \eta_{\text{cool}} / (1 - \text{TDL}_{\text{elec}})$$

η_{cool} = Cooling system efficiency = 3.52.¹¹

Change in Cooling load:

$$\Delta E_{\text{cl}} = (\text{WHCF} \times \% \text{Conditioned} \times \% \text{Cool}) \times ((\text{HR}_{\text{base}} \times E_{\text{dryer,base}}) - (\text{HR}_{\text{hp}} \times E_{\text{dryer,hp}}))$$

WHCF = Portion of waste heat that results in increased cooling= 0.188¹²

%Cool = Presence of existing cooling¹³

Table 9. Percentage of C/I Customers with Cooling

| Air Conditioning? | %Cool |
|-------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

⁹ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer , page 179, footnote 14

¹⁰ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 176, footnote 2

¹¹ Because of the large diversity of cooling types in C/I buildings, it is difficult to estimate the average efficiency. Accordingly, and because cooling is a non-thermal sector end use, a coefficient of performance (COP) of 3.52 is assumed, equivalent to 1 kW/ton and 12 SEER.

¹² Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 178, footnote 13

¹³ Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England

Common Inputs

%HR = Proportion of dryer heat energy remaining in space. Baseline dryer may be vented or ventless depending on model; assume vented if unknown. Heat pump clothes dryers are ventless.

Table 10. Portion of Dryer Heat Energy Remaining in Space

| Dryer Type | %HR ¹⁴ |
|------------|-------------------|
| Vented | 5% |
| Ventless | 100% |

3.6 = MJ per kWh

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is estimated to be 10 years.¹⁵

MEASURE COST

The market opportunity incremental cost is \$61 for ENERGY STAR units and \$412 for ENERGY STAR Most Efficient Units.¹⁶

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Existing dryer fuel
- Heat pump dryer size (standard or compact)
- ENERGY STAR Most Efficient certification status
- Setting where HPCD installed (coin-operated laundromats, multifamily common areas, or on-premise laundromats)
 - Estimated number of cycles per year, for other settings (N_{cycles})

¹⁴ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. Source reference not provided.

¹⁵ The New York TRM V11 estimates 14 years for clothes dryers in commercial settings. The Efficient Vermont TRM Program Year 2023 deems a lifetime of 12 years for residential clothes dryers. Because of the heavier usage, a residential grade dryer in a commercial setting would be expected to have a lower measure life. Therefore, the measure life was decreased to 10 years.

¹⁶ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. "See "2023 Clothes Dryer Analysis_v2.xlsx", "Incremental Cost" tab. Based on DOE Life-Cycle Cost and Payback Period analysis Table

8.3.1, <http://www.regulations.gov/contentStreamer?objectId=0900006480c8ee12&disposition=attachment&contentType=pdf>

For greater accuracy, the following variables could also be collected:

- Efficient dryer technology (heat pump or hybrid heat pump)
- Primary space heating fuel
- Presence of central cooling
- Existing dryer venting (vented or ventless)

ENERGY CODES AND STANDARDS

Minimum efficiencies for residential clothes dryers are prescribed in 10 CFR § 430.32.

Installed dryers must be ENERGY STAR-certified to qualify for this characterization. As of August 2024, Version 1.1 of the ENERGY STAR Program Requirements Product Specification for Clothes Dryers is in effect.

2.1.2 INDUCTION COOKTOP

CHS Measure ID: CI_APPL_INCT

Market Sector: Commercial/Industrial

End Use: Appliances

Applicable Building Types: Non-Residential

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural gas, propane, electricity

Decision/Action Type: Retrofit, MOP

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of an induction cooktop in a commercial kitchen to replace a conventional gas cooktop. Induction cooktops use electric induction to efficiently convert electrical energy to thermal energy. CO₂e savings are achieved through switching from fossil fuel usage to electricity for cooking, and through the high efficiency of an induction cooktop compared to conventional gas or electric cooktops.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical conventional cooktop consuming a representative mix of natural gas, propane, and electricity. This scenario is suitable for Downstream offerings in which the baseline dryer fuel is not collected.
2. A conventional natural gas or propane cooktop. This scenario is suitable for Downstream offerings in which the baseline dryer fuel is collected.

Proposed Conditions

The proposed condition is an electric induction cooktop.

ELIGIBILITY CRITERIA

The installed cooktop is electric induction.

This characterization is intended for fuel switching scenarios. Standard electric cooktops are only considered as a baseline component when the baseline cooktop fuel is not collected.

DECARBONIZATION SUMMARY

Table 11 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- 143 lbs of food cooked per day
- Days of operation per year = 326

Table 11. Example Induction Cooktop CO2e Reductions

| Existing Cooktop | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
|------------------|--|-------------------------------------|------------------|
| Natural Gas | 14,752,716,216 | 14,752,716,216 | 14,752.7 |
| Propane | 17,175,866,943 | 17,175,866,943 | 17,175.9 |
| Unknown | 6,481,233,644 | 6,481,233,644 | 6,481.2 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{induction}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] of baseline cooktop:}$$

If baseline dryer fuel is known:

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{load}} / \eta_{\text{base,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural Gas: CO2e}_{\text{base}} = (E_{\text{load}} / \eta_{\text{base,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\%LP_{\text{cook}} \times E_{\text{load}}) / \eta_{\text{base,LP}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) + ((\%NG_{\text{cook}} \times E_{\text{base,NG}} \times CI_{\text{NG}}) / \eta_{\text{base,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\%Elec_{\text{cook}} \times E_{\text{base,elec}} \times CI_{\text{elec}}) / \eta_{\text{base,elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$\%LP_{\text{cook}}$, etc. = Relative proportion of cooktop fuel in Vermont non-residential buildings. See Table 12.¹⁷

$$\eta_{\text{base,fuel}} = \text{Baseline cooktop efficiency}^{18}$$

¹⁷ US Energy Information Administration, Commercial Buildings Energy Consumption Survey, 2018. Table B11.

¹⁸ Illinois TRM v12, C/I Efficient Cooktops. Source: Frontier Energy, Inc. 2023. "Cooktop_Supporting_Data_R2 2023-07-30.xlsx".

Table 12. Assumed Cooktop Fuel Mix in Vermont Non-Residential Buildings and Baseline Cooktop Efficiency

| Cooktop Fuel | %Fuel _{cook} | η _{base,fuel} |
|--------------|-----------------------|------------------------|
| Propane | 7.5% | 34% |
| Natural Gas | 34.2% | 34% |
| Electricity | 57.3% | 75% |

$$\begin{aligned} \text{CO2e}_{\text{induction}} &= \text{Annual CO2e emissions of electric induction cooktop} \\ &= (E_{\text{load}} / \eta_{\text{induction}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}}) \end{aligned}$$

$$\eta_{\text{induction}} = 84\%.^{19}$$

Non-Thermal Sector CO2e Impacts: None

Common Inputs

$$E_{\text{load}} = \text{Annual cooking load [MJ]} = \text{EPD} \times \text{Days}$$

$$\text{EPD} = \text{Energy per day [MJ]} = \text{Food} \times E_{\text{abs}}$$

Food = Pounds of food cooked per day [lb/day]. Use actual or assume 143 if unknown.²⁰

E_{abs} = ASTM energy to food ratio: the energy absorbed by the food during cooking [Btu/lb] = 130.²¹

Days = Annual days of operation. Use actual or 326 days per year if unknown.²²

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The measure life for an induction cooktop is 15 years.²³

MEASURE COST

Retrofit:

- The actual installed cost of the induction cooktop should be used if possible; if unknown, assume \$2,100.

¹⁹ Ibid.

²⁰ Ibid.

²¹ Ibid.

²² Ibid.

²³ 2023 Vermont Tier III TRM, Residential Induction Stovetop. "Energy Conservation Program: Energy Conservation Standards for Residential Conventional Oven, 2015, Department of Energy, Page 103, residential_ovens_nopr.pdf"

MOP:

- Assume an incremental cost of \$300 for replacing standard electric cooktops, and \$200 for replacing natural gas or propane cooktops. ²⁴
- Assume an incremental cost of \$247 if the existing cooktop fuel is unknown.²⁵

PROGRAM DATA TRACKING RECOMMENDATIONS

Downstream program designs should track the existing cooktop fuel.

ENERGY CODES AND STANDARDS

10 CFR 430.32(j)(1) prescribes maximum integrated annual energy consumption (IAEC) for electric and gas cooktops.

²⁴ Energy+Environmental Economics. *Residential Building Electrification in California: Consumer economics, greenhouse gases and grid impacts*. April 2019. Figure 2-8, p. 34. Induction stovetops: midpoint of \$1,900-\$2,300 range; gas stovetops: midpoint of \$1,400-\$2,200 range; standard electric stovetops: midpoint of \$1,700-\$2,100 range.

²⁵ Weighted-average of electric, natural gas, and propane incremental costs using unknown building type mix in Table 2.

2.2 BUILDING ENVELOPE

2.2.1 AIR SEALING

CHS Measure ID: CI_ENVE_AIRS

Market Sector: Commercial/Industrial

End Use: Envelope

Applicable Building Types: Non-Residential

Decarbonization Pathways: Weatherization

Applicable Baseline Fuels: Natural gas, propane, fuel oil #2, electricity, wood

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves sealing the envelope of a building to prevent air leakage. Air sealing measures include applying spray foam, weatherstripping, and caulking to seal gaps in the thermal envelope that allow air to leak in or out. Air leakage leads to heat loss, which causes the heating system to have to run more to maintain the temperature setpoint. Air leakage also has negative non-energy impacts in the form of comfort issues and can lead to physical damage to the building as a result of ice dams, which are caused in part by air leakage around unsealed attic protrusions such as chimneys, plumbing stacks, and electrical wiring.

This characterization quantifies the thermal energy savings and associated emission reductions based on pre- and post-blower door readings. A blower door is an industry-standard tool for measuring the total air leakage in a building. This is a Retrofit measure in which the baseline is the existing air leakage of the building, and the proposed condition is the leakage after air sealing measures are installed. This characterization is not applicable to gut rehab/major renovation projects, which may be subject to code requirements that set a more stringent baseline condition.

This characterization is primarily intended for small commercial settings; therefore the residential degree day assumptions are applied. Buildings where extensive air sealing is installed may require installation of a mechanical ventilation system such as an Energy Recovery Ventilator (ERV) or Heat Recovery Ventilator (HRV) to maintain acceptable indoor air quality.

In addition to heating-related emissions reductions which are eligible for clean heat credits, this characterization provides algorithms for cooling and fan/pump-energy related emissions reductions which are not eligible for credits.

Baseline Conditions

The baseline is the total air leakage volume prior to installing air sealing measures, measured with a blower door test.

Proposed Conditions

The proposed condition is the total air leakage volume after installing air sealing measures, measured with a blower door test.

ELIGIBILITY CRITERIA

Pre- and post-blower door tests are required to apply this characterization.

DECARBONIZATION SUMMARY

Table 13 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Central A/C presence is unknown/not collected
- Heating efficiencies per Table 14

Table 13. Example C/I Air Sealing CO₂e Reductions

| CFM50 Reduction | | Heating Fuel | Lifetime CO ₂ e Reductions, Thermal [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------|---------------|--------------|--|--|------------------|
| Range | Assumed Value | | | | |
| > 0 and < 800 | 400 | Oil | 3,433,379 | 3,461,531 | 3.4 |
| | | Propane | 2,794,475 | 2,821,227 | 2.8 |
| | | Natural Gas | 2,451,765 | 2,478,517 | 2.5 |
| | | Electricity | 187,804 | 202,261 | 0.2 |
| | | Wood | 1,677,614 | 1,707,172 | 1.7 |
| | | Unknown | 1,943,544 | 1,966,477 | 1.9 |
| 800 to < 1600 | 1200 | Oil | 10,300,138 | 10,384,592 | 10.3 |
| | | Propane | 8,383,425 | 8,463,682 | 8.4 |
| | | Natural Gas | 7,355,295 | 7,435,552 | 7.4 |
| | | Electricity | 563,411 | 606,782 | 0.6 |
| | | Wood | 5,032,843 | 5,121,517 | 5.0 |
| | | Unknown | 5,830,633 | 5,899,431 | 5.8 |
| > 1600 | 2000 | Oil | 17,166,897 | 17,307,653 | 17.2 |
| | | Propane | 13,972,375 | 14,106,136 | 14.0 |
| | | Natural Gas | 12,258,825 | 12,392,586 | 12.3 |
| | | Electricity | 939,019 | 1,011,304 | 0.9 |
| | | Wood | 8,388,072 | 8,535,862 | 8.4 |
| | | Unknown | 9,717,722 | 9,832,385 | 9.7 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Total annual carbon dioxide equivalent emissions reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{heat}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

CreditValue = 1 credit/tonneCO2e

1,000,000 = Grams per metric ton

$\Delta\text{CO2e}_{\text{heat}}$ = CO2e emissions reductions [g] from reducing heating energy

If primary heating fuel is known:

$$\text{Oil: } \Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{ave,oil}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{ave,LP}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: } \Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,NG}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Wood: } \Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{ave,wood}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})$$

$$\text{Electricity: } \Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,elec}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

If primary heating fuel is unknown:

$$\Delta\text{CO2e}_{\text{heat}} = (\% \text{Oil} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}}) / \eta_{\text{ave,oil}}) + (\% \text{LP} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}}) / \eta_{\text{ave,LP}}) + (\% \text{NG} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{NG}} / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + (\% \text{Wood} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})) / \eta_{\text{ave,wood}}$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 14) ²⁶

$\eta_{\text{ave,oil}}$, etc. = Average heating efficiency for each fuel type [dimensionless] (see Table 14) ²⁷

Table 14. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | C/I Sector % | Average Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|--------------|---|
| Oil | 15% | 0.81 |
| Propane (LP) | 29% | 0.88 |
| Natural Gas (NG) | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$\Delta E_{\text{hl}} = \text{Reduction in heating load [MJ]} = [(1.08 \times (\text{CFM50}_{\text{pre}} - \text{CFM50}_{\text{post}}) / N \times \text{Adj}_{\text{heat}} \times \text{HDH})] \times 0.00106$$

Adj_{heat} = Heating adjustment factor to reconcile this simplified algorithm with evaluation bill analysis results = 0.55 [dimensionless].²⁸

²⁶ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. "Other" fuel category removed.

²⁷ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

²⁸ Efficiency Vermont TRM Program Year 2023, HPwES 2.0 Airsealing. "This adjustment factor mirrors that which is applied to HERO-based HPwES projects. Based on the 2018 program impact evaluation and subsequent outcomes of EM&V/DPS negotiations, the 0.55 adjustment factor is

$$\text{HDH} = \text{Heating degree hours } [^{\circ}\text{F hr}] = 113,443.^{29}$$

Non-Thermal Sector CO2e Impacts:

$$\Delta\text{CO2e}_{\text{cool}} = \text{CO2e reductions [g] from decreased cooling energy} = (\Delta E_{\text{cl}} / \eta_{\text{cool}} \times \text{Cl}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cl}} = \text{Reduction in cooling load [MJ]} = [\% \text{Cool} \times (1.08 \times (\text{CFM50}_{\text{pre}} - \text{CFM50}_{\text{post}}) / \text{N} \times \text{Adj}_{\text{cool}} \times \text{CDH})] \times 0.00106$$

%Cool = Presence of existing cooling. ³⁰

| Existing Cooling? | %Cool |
|-------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

Adj_{cool} = Cooling adjustment factor to account for people not always operating their air-conditioning systems when the outside temperature is greater than 75 °F = 0.75 [dimensionless].³¹

$$\text{CDH} = \text{Cooling degree hours } [^{\circ}\text{F hr}] = 6,619.^{32}$$

$$\eta_{\text{cool}} = \text{Cooling system efficiency} = 3.52.^{33}$$

$$\Delta\text{CO2e}_{\text{fan}} = \text{CO2e reductions [g] from decreased furnace fan or boiler pump energy} = (\Delta E_{\text{fan}} \times \text{Cl}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{fan}} = \text{Reduction in furnace fan or boiler pump energy [MJ]}$$

If heating fuel is known:

$$\Delta E_{\text{fan}} = \% \text{Fossil} \times \Delta E_{\text{hl}} / \eta_{\text{heat}} \times F_e$$

intended to better align the savings estimated by HERO algorithms to those established by evaluation. Since the algorithms used by this characterization closely align with HERO, the same adjustment factor is adopted.”

²⁹ Efficiency Vermont TRM 2023, HPwES 2.0 Airsealing, calculated as average of flat, open attic (127,691 °F-hr) and basement/crawlspace rim joists and walls (99,195 °F-hr). “Heating Degree Hours for attic assumes a base temperature of 58 degrees F and uses Climate Normals data for Burlington International Airport. A recent Nest study by EVT revealed that a base temperature of 58 degrees is appropriate to capture the heating tendencies of a typical Vermont home. See referenced document “NEST VEIC Data Share 9Jun2017”. In an attempt to make a conservative estimate of heating degree hours, it was assumed that only days within a defined heating season would be included in the total, assuming that homeowners would disable or set back heating systems in the off season. The heating season was defined as the time period where temperatures “consistently” fall below 58 degrees. Based on visual inspection of TMY3 data, this period was established as September 19th to May 6th. Heating Degree Hours for basement assumes a blend of conditioned and unconditioned space as reported by the Vermont Single-Family Existing Homes On-Site Report, December 21, 2017. Unconditioned space HDH assumes a base temperature of 48 degrees F based on the premise that unconditioned basements are allowed to swing in temperature, are ground coupled, and are usually cool. See worksheets “Foundation Blend” and “HDH - Climate Normals” in the ‘HPwES 2.0 Support Workbook FINAL_2022’ for a complete derivation.”

³⁰ Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England

³¹ Energy Center of Wisconsin, *Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research*, 2008, page 31.

³² Efficiency Vermont TRM Program Year 2023, ERV/HRV. “Based on analysis of TMY data with 70 °F base temperature. See the ‘Weather data’ sheet of ERV_HRV_Analysis_2022.xlsx for more details.”

³³ Because of the large diversity of cooling types in C/I buildings, it is difficult to estimate the average efficiency. Accordingly, and because cooling is a non-thermal sector end use, a coefficient of performance (COP) of 3.52 is assumed, equivalent to 1 kW/ton and 12 SEER.

If heating fuel is unknown:

$$\Delta E_{fan} = \%Fossil \times (\%Oil \times \Delta E_{hl} / \eta_{ave,oil}) + (\%LP \times \Delta E_{hl} / \eta_{ave,LP}) + (\%NG \times \Delta E_{hl} / \eta_{ave,NG}) + (\%Elec \times \Delta E_{hl} / \eta_{ave,elec}) + (\%Wood \times \Delta E_{hl} / \eta_{ave,wood}) \times F_e$$

%Fossil = Presence of fossil-fuel furnace or boiler (from Table 14).

| Fossil Fuel System? | %Fossil |
|---------------------|---------|
| Yes | 100% |
| No | 0% |
| Unknown | 66% |

F_e = Furnace/boiler fan/pump energy as a percentage of annual fuel consumption = 3.14%.³⁴

Common Inputs:

CFM50_{pre} = Pre-installation blower door reading in cubic feet per minute, measured at 50 Pascals pressure differential.

CFM50_{post} = Post-installation blower door reading in cubic feet per minute, measured at 50 Pascals pressure differential.

N = Conversion factor from volumetric airflow at 50 Pascals differential pressure to airflow at natural conditions = 17.1 [dimensionless].³⁵

1.08 = Specific heat of air x density of air x 60 min/hr [BTU/(CFM °F hr)]

0.00106 = MJ per BTU.

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] ((see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

Lifetime for air sealing is 20 years.³⁶

MEASURE COST

³⁴ Illinois TRM v12.0. "F_e is not one of the AHRI certified ratings provided for residential furnaces, but can be reasonably estimated from a calculation based on the certified values for fuel energy (E_f in MMBTU/yr) and E_{ae} (kWh/yr). An average of a 300 record sample (non-random) out of 1495 was 3.14%."

³⁵ Sherman, M.H. "Estimation of Infiltration from Leakage and Climate Indicators". *Energy and Buildings*, 10 (1987). Vermont is in zone 2, where N₀ varies between 17-19. A conservative value of 19 is assumed, consistent with New York TRM v11.0. Assumes average building height of 1.5 stories (height correction factor of 0.9), normal shielding (correction factor of 1.0), and normal leakage (correction factor of 1.0). N = 19 x 0.9 x 1.0 x 1.0 = 17.1.

³⁶ Illinois TRM v12.0. As recommended in Navigant 'ComEd Effective Useful Life Research Report', May 2018.

Measure cost of \$3,000 per job is assumed for air sealing.³⁷

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Heating fuel type
- Pre-installation blower door measurement at 50 Pascals pressure differential (CFM50_{pre})
- Post-installation blower door measurement at 50 Pascals pressure differential (CFM50_{post})

For greater accuracy, the following variables could additionally be collected:

- Central cooling presence

ENERGY CODES AND STANDARDS

This characterization is code-agnostic; however, implementers should comply with any and all local code requirements concerning insulation standards.

2.2.2 BUILDING SHELL INSULATION

CHS Measure ID: CI_ENVE_INSU

Market Sector: Commercial/Industrial

End Use: Envelope

Applicable Building Types: Non-Residential

Decarbonization Pathways: Weatherization

Applicable Baseline Fuels: Natural gas, propane, fuel oil #2, electricity, wood

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves adding insulation to building shell assemblies to reduce conductive heat loss to the outside. It is a Retrofit measure in which the baseline is the thermal resistance of the assembly prior to the installation and the proposed condition is the thermal resistance of the structure after the installation. This characterization may be applied to sloped ceiling, attic, above grade walls, and below grade walls. This characterization calculates CO₂e savings on a per square foot basis from actual pre- and post- R-values for insulation alone.

This characterization is primarily intended for small commercial settings; therefore the residential degree day assumptions are applied. In addition to heating-related emissions reductions which are eligible for clean heat credits, this characterization provides algorithms for cooling and fan/pump-energy related emissions reductions which are not eligible for credits.

Baseline Conditions

The baseline is the R-value of the assembly prior to the retrofit. The assembly may have some existing insulation or none.

Proposed Conditions

The proposed condition is the R-value of the assembly after the retrofit. This characterization does not require a minimum level of insulation following the retrofit.

ELIGIBILITY CRITERIA

At a minimum, the interior space must be mechanically heated and maintained continuously at typical comfort temperatures.

DECARBONIZATION SUMMARY

Table 15 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Central A/C presence is unknown/not collected
- Heating efficiencies per Table 16

Table 15. Example C/I Building Shell Insulation CO2e Reductions

| Assembly Type | Heating Fuel | R-Value of Insulation Alone | | Lifetime CO2e Reductions per SF, Thermal [g/ft ²] | Lifetime CO2e Reductions per SF, Total [g/ft ²] | Lifetime Credits Per SF |
|--------------------------------------|--------------|-----------------------------|----------|---|---|-------------------------|
| | | Baseline | Proposed | | | |
| Attic, Standard Wood Framing | Oil | None | R-49 | 92,590 | 93,317 | 0.1 |
| | Propane | None | R-49 | 75,361 | 76,050 | 0.1 |
| | Natural Gas | None | R-49 | 66,119 | 66,808 | 0.1 |
| | Electricity | None | R-49 | 5,065 | 5,422 | 0.0 |
| | Wood | None | R-49 | 45,241 | 46,006 | 0.0 |
| | Unknown | None | R-49 | 52,413 | 52,999 | 0.1 |
| Exterior Wall, Standard Wood Framing | Oil | None | R-15 | 36,977 | 37,267 | 0.0 |
| | Propane | None | R-15 | 30,096 | 30,371 | 0.0 |
| | Natural Gas | None | R-15 | 26,405 | 26,680 | 0.0 |
| | Electricity | None | R-15 | 2,023 | 2,165 | 0.0 |
| | Wood | None | R-15 | 18,067 | 18,373 | 0.0 |
| | Unknown | None | R-15 | 20,931 | 21,165 | 0.0 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$\Delta\text{CO2e}_{\text{thermal}}$ = Total annual carbon dioxide equivalent emissions reductions in grams [g] = $\Delta\text{CO2e}_{\text{heat}}$

Annual Clean Heat Credits = $\Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$

CreditValue = 1 credit/tonneCO2e

1,000,000 = Grams per metric ton

$\Delta\text{CO2e}_{\text{heat}}$ = CO2e emissions reductions [g] from reducing heating energy

If primary heating fuel is known:

$$\text{Oil: } \Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{ave,oil}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{ave,LP}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: } \Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,NG}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Wood: } \Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{ave,wood}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})$$

$$\text{Electricity: } \Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,elec}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

If primary heating fuel is unknown:

$$\Delta\text{CO}_2e_{\text{heat}} = (\% \text{Oil} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}}) / \eta_{\text{ave,oil}}) + (\% \text{LP} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}}) / \eta_{\text{ave,LP}}) + (\% \text{NG} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{NG}} / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + (\% \text{Wood} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})) / \eta_{\text{ave,wood}}$$

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 16) ³⁸

$\eta_{\text{ave,fuel}}$ = Average heating efficiency for each fuel type [dimensionless] (see Table 16) ³⁹

Table 16. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | C/I Sector % | Average Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|--------------|---|
| Oil | 15% | 0.81 |
| Propane (LP) | 29% | 0.88 |
| Natural Gas (NG) | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$\Delta E_{\text{hl}} = \text{Reduction in heating load [MJ]} = ((1/R_{\text{pre}} - 1/R_{\text{post}}) \times A_{\text{ins}} \times \text{HDH} \times \text{Adj}_{\text{heat}}) \times 0.00106$$

HDH = Heating degree hours [$^{\circ}\text{F hr}$], dependent on structure being treated (see below) ⁴⁰

| Structure | HDH [$^{\circ}\text{F hr}$] |
|------------------------------|-------------------------------|
| Flat attic or sloped ceiling | 127,961.3 |
| Exterior walls | |
| Basement walls | 99,194.6 |

Adj_{heat} = Heating adjustment factor to reconcile this simplified algorithm with evaluation bill analysis results = 0.55 [dimensionless].⁴¹

Non-Thermal Sector CO2e Impacts:

$$\Delta\text{CO}_2e_{\text{cool}} = \text{CO}_2e \text{ reductions [g]} \text{ from decreased cooling energy} = (\Delta E_{\text{cl}} / \eta_{\text{cool}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cl}} = \text{Reduction in cooling load [MJ]} = (\% \text{Cool} \times (1/R_{\text{pre}} - 1/R_{\text{post}}) \times A_{\text{ins}} \times \text{CDH} \times \text{Adj}_{\text{cool}}) \times 0.00106$$

³⁸ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed.

³⁹ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

⁴⁰ NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, statewide mean values for each system type/fuel from Appendix A, except propane furnace efficiency carried forward from Efficiency Vermont TRM Program Year 2023, HPwES 2.0 Insulation: Attic and/or Basement.

⁴¹ Efficiency Vermont TRM Program Year 2023, HPwES 2.0 Insulation: Attic and/or Basement, page 302, footnote 5.

%Cool = Presence of existing cooling. ⁴²

| Existing Cooling? | %Cool |
|-------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

Adj_{cool} = Cooling adjustment factor to account for people not always operating their air-conditioning systems when the outside temperature is greater than 75 °F = 0.75 [dimensionless].⁴³

CDH = Cooling degree hours [°F hr] = 6,619.⁴⁴

η_{cool} = Cooling system efficiency = 3.52.⁴⁵

ΔCO_{2e}_{fan} = CO_{2e} reductions [g] from decreased furnace fan or boiler pump energy = (ΔE_{fan} x C_{Ielec})/(1-TD_{Lelec})

ΔE_{fan} = Reduction in furnace fan or boiler pump energy [MJ]

If heating fuel is known:

$$\Delta E_{fan} = \%Fossil \times \Delta E_{hl} / \eta_{heat} \times F_e$$

If heating fuel is unknown:

$$\Delta E_{fan} = \%Fossil \times ((\%Oil \times \Delta E_{hl} / \eta_{ave,oil}) + (\%LP \times \Delta E_{hl} / \eta_{ave,LP}) + (\%NG \times \Delta E_{hl} / \eta_{ave,NG}) + (\%Elec \times \Delta E_{hl} / \eta_{ave,elec}) + (\%Wood \times \Delta E_{hl} / \eta_{ave,wood})) \times F_e$$

%Fossil = Presence of fossil-fuel furnace or boiler (from Table 16).

| Fossil Fuel System? | %Fossil |
|---------------------|---------|
| Yes | 100% |
| No | 0% |
| Unknown | 66% |

F_e = Furnace/boiler fan/pump energy as a percentage of annual fuel consumption = 3.14%.⁴⁶

Common Inputs:

R_{pre} = Pre-installation R-value [(ft² °F hr)/Btu] of assembly, derived from tables below. For alternate construction types, refer to ASHRAE 90.1 Appendix A.

⁴² Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England

⁴³ Energy Center of Wisconsin, *Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research*, 2008, page 31.

⁴⁴ *Efficiency Vermont TRM Program Year 2023*, ERV/HRV. “Based on analysis of TMY data with 70 °F base temperature. See the 'Weather data' sheet of ERV_HRV_Analysis_2022.xlsx for more details.”

⁴⁵ Because of the large diversity of cooling types in C/I buildings, it is difficult to estimate the average efficiency. Accordingly, and because cooling is a non-thermal sector end use, a coefficient of performance (COP) of 3.52 is assumed, equivalent to 1 kW/ton and 12 SEER.

⁴⁶ Illinois TRM v12.0. “F_e is not one of the AHRI certified ratings provided for residential furnaces, but can be reasonably estimated from a calculation based on the certified values for fuel energy (E_f in MMBTU/yr) and E_{ae} (kWh/yr). An average of a 300 record sample (non-random) out of 1495 was 3.14%.”

R_{post} = Post-installation R-value [(ft² °F hr)/Btu] of assembly, derived from tables below. For alternate construction types, refer to ASHRAE 90.1 Appendix A.⁴⁷

Table 17. C/I Insulation: Assembly R-Factors for Attic Roofs with Wood Joists

| Rated R-Value of Insulation Alone | Overall R-Factor For Entire Assembly (R_{pre} , R_{post}) |
|--|---|
| Wood-Framed Attic, Standard Framing | |
| None | R-1.6 |
| R-11 | R-11.0 |
| R-13 | R-12.3 |
| R-19 | R-18.9 |
| R-30 | R-29.4 |
| R-38 | R-37.0 |
| R-49 | R-47.6 |
| R-60 | R-58.8 |

Table 18. C/I Insulation: Assembly R-Factors for Wood-Frame Walls

| Framing Type and Spacing Width (Actual Depth) | Cavity Insulation R-Value: Rated | Overall R-Factor For Entire Base Assembly | Overall R-Factor for Assembly of Base Wall Plus Continuous Insulation (Uninterrupted by Framing) (R_{pre} , R_{post}) | | | | |
|---|----------------------------------|---|---|--------|--------|--------|--------|
| | | | Rated R-Value of Continuous Insulation | | | | |
| | | | R-1.00 | R-2.00 | R-3.00 | R-4.00 | R-5.00 |
| Wood Studs at 16 in. on Center | | | | | | | |
| 3.5 in. depth | None | R-3.4 | R-4.5 | R-5.5 | R-6.6 | R-7.6 | R-8.6 |
| | R-11 | R-10.4 | R-11.5 | R-12.7 | R-13.7 | R-14.7 | R-15.9 |
| | R-13 | R-11.2 | R-12.5 | R-13.5 | R-14.7 | R-15.9 | R-16.9 |
| | R-15 | R-12.0 | R-13.3 | R-14.5 | R-15.6 | R-16.7 | R-17.9 |
| 5.5 in. depth | R-19 | R-14.9 | R-16.1 | R-17.2 | R-18.5 | R-19.6 | R-20.8 |
| | R-21 | R-15.9 | R-17.2 | R-18.5 | R-19.6 | R-20.8 | R-22.2 |
| + R-10 headers | R-19 | R-15.9 | R-16.9 | R-18.2 | R-19.2 | R-20.4 | R-21.3 |
| | R-21 | R-16.9 | R-18.2 | R-19.6 | R-20.4 | R-21.7 | R-22.7 |

⁴⁷ Insulation tables are derived from ASHRAE 90.1-2016 Normative Appendix A. Commercial/Industrial Installed Measures Building Envelope - Building Shell Insulation

| | | | | | | | | | |
|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|
| R-6.00 | R-7.00 | R-8.00 | R-9.00 | R-10.00 | R-11.00 | R-12.00 | R-13.00 | R-14.00 | R-15.00 |
| R-9.6 | R-10.6 | R-11.6 | R-12.7 | R-13.7 | R-14.7 | R-15.6 | R-16.7 | R-17.9 | R-18.9 |
| R-16.9 | R-17.9 | R-18.9 | R-20.0 | R-20.8 | R-21.7 | R-22.7 | R-23.8 | R-25.0 | R-26.3 |
| R-17.9 | R-18.9 | R-20.0 | R-21.3 | R-22.2 | R-23.3 | R-24.4 | R-25.0 | R-26.3 | R-27.0 |
| R-18.9 | R-20.0 | R-21.3 | R-22.2 | R-23.3 | R-24.4 | R-25.6 | R-26.3 | R-27.8 | R-28.6 |
| R-21.7 | R-22.7 | R-23.8 | R-25.0 | R-26.3 | R-27.0 | R-27.8 | R-29.4 | R-30.3 | R-31.3 |
| R-23.3 | R-24.4 | R-25.6 | R-26.3 | R-27.8 | R-28.6 | R-29.4 | R-31.3 | R-32.3 | R-33.3 |
| R-22.2 | R-23.3 | R-24.4 | R-25.6 | R-26.3 | R-27.8 | R-28.6 | R-29.4 | R-30.3 | R-32.3 |
| R-23.8 | R-25.0 | R-26.3 | R-27.0 | R-28.6 | R-29.4 | R-30.3 | R-31.3 | R-32.3 | R-33.3 |

Table 19. C/I Insulation: Assembly R-Factors for Below-Grade Mass Walls

| Depth, in. | Framing Type | Rated R-Value of Insulation Alone | | | | | | | |
|---|--------------|-----------------------------------|-------|-------|-------|-------|--------|--------|--------|
| | | R-0 | R-2 | R-4 | R-6 | R-8 | R-10 | R-12 | R-14 |
| Effective Value if Continuous Insulation Uninterrupted by Framing (Includes Gypsum Board) | | | | | | | | | |
| | None | R-0.5 | R-2.5 | R-4.5 | R-6.5 | R-8.5 | R-10.5 | R-12.5 | R-14.5 |
| Effective Value if Insulation is Installed in Cavity Between Framing (Includes Gypsum Board) | | | | | | | | | |
| 1.5 | Wood | R-1.3 | R-2.4 | R-3.8 | R-4.9 | R-5.8 | R-6.5 | R-7.1 | NA |
| 3.5 | Wood | R-1.4 | R-2.6 | R-4.4 | R-6.0 | R-7.4 | R-8.7 | R-9.8 | R-10.9 |
| 5.5 | Wood | R-1.4 | R-2.6 | R-4.6 | R-6.4 | R-8.1 | R-9.6 | R-11 | R-12.4 |

| R-16 | R-18 | R-20 | R-22 | R-24 |
|--------|--------|--------|--------|--------|
| R-16.5 | R-18.5 | R-20.5 | R-22.5 | R-24.5 |
| NA | NA | NA | NA | NA |
| R-11.8 | R-12.6 | R-13.4 | R-14.1 | R-14.8 |
| R-13.6 | R-14.7 | R-15.8 | R-16.8 | R-17.8 |

A_{ins} = Area in square feet of insulation applied, from application.

1.08 = Specific heat of air x density of air x 60 min/hr [BTU/(CFM °F hr)]

0.00106 = MJ per BTU.

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

Lifetime for attic and sloped ceiling insulation is 30 years.

Lifetime for exterior wall insulation is 30 years.

Lifetime for basement insulation is 15 years.⁴⁸

MEASURE COST

Measure costs of \$3.5/sq ft is assumed for attic insulation.

Measure costs of \$6.0/sq ft is assumed for sloped ceiling insulation.

Measure costs of \$3,000 per job is assumed for basement insulation.

Measure costs of \$2/sq ft is assumed for wall insulation.⁴⁹

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Heating fuel type
- Heating system type
- Total square feet of insulation installed (A_{ins})
- Insulation location (attic/ceiling, exterior walls, basement wall)
- Framing type
- Pre- R-value of insulation alone
- Post- R-value of insulation alone

For greater accuracy, the following variables could additionally be collected:

- Central cooling presence

ENERGY CODES AND STANDARDS

N/A

⁴⁸ *Efficiency Vermont TRM Program Year 2023*, HPwES 2.0 Insulation: Attic and/or Basement, HPwES 2.0 Insulation: Exterior Walls.

⁴⁹ *Ibid.*

2.3 DOMESTIC HOT WATER

2.3.1 HEAT PUMP WATER HEATER

CHS Measure ID: CI_DOHW_HPWH

Market Sector: Commercial/Industrial

End Use: Domestic Hot Water

Applicable Building Types: Non-Residential, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves installation of a heat pump water heater to provide domestic hot water (DHW) in a C/I facility or in a multifamily building serving multiple dwelling units. Heat pump water heaters (HPWH) efficiently heat water by transferring heat through a vapor compression cycle instead of combusting fuel.

This characterization includes indirect space heating impacts as a result of the HPWH.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical conventional water heater consuming a representative mix of oil, natural gas, propane, and electricity. This scenario is suitable for Downstream offerings in which the baseline water heater fuel is not collected.
2. A minimum efficiency oil, natural gas or propane water heater. This scenario is suitable for Downstream offerings in which the baseline water heater fuel is collected.

Proposed Conditions

The proposed condition is an installed commercial HPWH.

ELIGIBILITY CRITERIA

To qualify, the installed HPWH must be a NEEA-certified Commercial/Multifamily HPWH (CHPWH) meeting at least Tier 1 system coefficient of performance (SysCOP):⁵⁰

⁵⁰ NEEA Advanced Water Heating Specification 8.1, <https://neea.org/img/documents/Advanced-Water-Heating-Specification.pdf>.

Table 20. NEEA CHPWH System Efficiency Tiers

| Tier | Minimum SysCOP, Cold Climates (IECC Zones 5-6) |
|--------|--|
| Tier 1 | 1.25 |
| Tier 2 | 1.60 |
| Tier 3 | 2.25 |
| Tier 4 | 2.75 |

This characterization is intended for fuel switching scenarios. Electric water heaters are only considered as a baseline component when the baseline water heater fuel is not collected.

DECARBONIZATION SUMMARY

Table 21 provides estimated lifecycle decarbonization ranges for example baseline and proposed conditions over the effective useful life of the measure. These estimates are not inclusive of all eligible possibilities; other values may be calculated from the following algorithms.

Assumptions:

- Average baseline water heater efficiencies per Table 22
- Average space heating efficiencies per Table 22
- Tier 1 CHPWH, SysCOP = 1.25
- Small office building, 110 gallons of DHW consumed daily

Table 21. Example C/I Heat Pump Water Heater CO₂e Reductions

| Baseline Water Heating Fuel | Proposed Equipment | Space Heating Fuel | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------------------|--------------------|--------------------|---|--|------------------|
| Oil | CHPWH Tier 1 | Oil | 16,112,680 | 16,527,229 | 16.1 |
| | | Propane | 19,232,311 | 19,646,861 | 19.2 |
| | | Natural Gas | 20,914,191 | 21,328,740 | 20.9 |
| | | Electricity | 31,704,581 | 32,119,131 | 31.7 |
| | | Wood | 26,496,707 | 26,911,257 | 26.5 |
| | | Unknown | 23,304,671 | 23,719,220 | 23.3 |
| Propane | CHPWH Tier 1 | Oil | 11,400,146 | 11,814,695 | 11.4 |
| | | Propane | 14,519,777 | 14,934,327 | 14.5 |
| | | Natural Gas | 16,201,657 | 16,616,207 | 16.2 |
| | | Electricity | 26,992,047 | 27,406,597 | 27.0 |
| | | Wood | 21,784,173 | 22,198,723 | 21.8 |
| | | Unknown | 18,592,137 | 19,006,686 | 18.6 |

| Baseline Water Heating Fuel | Proposed Equipment | Space Heating Fuel | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
|-----------------------------|--------------------|--------------------|--|-------------------------------------|------------------|
| Natural Gas | CHPWH Tier 1 | Oil | 6,967,147 | 7,381,696 | 7.0 |
| | | Propane | 10,086,778 | 10,501,328 | 10.1 |
| | | Natural Gas | 11,768,658 | 12,183,208 | 11.8 |
| | | Electricity | 22,559,049 | 22,973,598 | 22.6 |
| | | Wood | 17,351,174 | 17,765,724 | 17.4 |
| | | Unknown | 14,159,138 | 14,573,687 | 14.2 |
| Unknown | CHPWH Tier 1 | Oil | 509,246 | 923,796 | 0.5 |
| | | Propane | 3,628,878 | 4,043,427 | 3.6 |
| | | Natural Gas | 5,310,758 | 5,725,307 | 5.3 |
| | | Electricity | 16,101,148 | 16,515,698 | 16.1 |
| | | Wood | 10,893,274 | 11,307,823 | 10.9 |
| | | Unknown | 7,701,237 | 8,115,787 | 7.7 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}} + \Delta\text{CO2e}_{\text{heat}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HPWH}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline water heater}$$

If baseline water heater fuel is known:

$$\text{Oil: } \Delta\text{CO2e}_{\text{heat}} = Q_{\text{load}} / \text{EF}_{\text{ave,oil}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \Delta\text{CO2e}_{\text{heat}} = Q_{\text{load}} / \text{EF}_{\text{ave,LP}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: } \Delta\text{CO2e}_{\text{heat}} = Q_{\text{load}} / \text{EF}_{\text{ave,NG}} \times \text{CI}_{\text{NG}} / (1 - \text{TDL}_{\text{NG}})$$

If baseline water heater fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil}_{\text{WH}} \times Q_{\text{load}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{EF}_{\text{ave}}) + ((\% \text{LP}_{\text{WH}} \times Q_{\text{load}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \text{EF}_{\text{ave}}) + ((\% \text{NG}_{\text{WH}} \times Q_{\text{load}} \times \text{CI}_{\text{NG}}) / \text{EF}_{\text{ave}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec}_{\text{WH}} \times Q_{\text{load}} \times \text{CI}_{\text{elec}}) / \text{EF}_{\text{ave}}) / (1 - \text{TDL}_{\text{elec}})$$

%Oil_{WH}, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 22)⁵¹

EF_{ave,fuel} = Average water heater efficiency [dimensionless] by fuel. See Table 22.⁵²

Table 22. Vermont Water Heating Fuel Mix and Average Efficiency, C/I Buildings

| Water Heating Fuel | %Fuel _{WH} | Average Efficiency (EF _{ave,fuel}) |
|--------------------|---------------------|--|
| Oil | 11% | 0.77 |
| Propane (LP) | 32% | 0.77 |
| Natural Gas (NG) | 15% | 0.77 |
| Electricity | 42% | 0.94 |

CO_{2e}_{HPWH} = Annual CO_{2e} emissions [g] from heat pump water heater = (Q_{load} / SysCOP x CI_{elec}) / (1 - TDLelec)

SysCOP = NEEA HPWH Cool Climate Efficiency (CCE) rating. Use actual or assume minimum CCE based on tier (see Table 20).

ΔCO_{2e}_{heat} = Change in CO_{2e} emissions [g] due to impact of heat pump water heater on space heating load. Heat pump water heaters produce an ambient cooling effect which results in an increase in space heating load, which reduces the overall CO_{2e} reductions.

If primary space heating fuel is known:

$$\text{Oil: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,NG}}) \times (\text{CI}_{\text{NG}} / (1 - \text{TDL}_{\text{NG}}))$$

$$\text{Electricity: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,elec}}) \times (\text{CI}_{\text{elec}} / (1 - \text{TDL}_{\text{elec}}))$$

$$\text{Wood: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,wood}}) \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})$$

If primary space heating fuel is unknown:

$$\Delta\text{CO}_2\text{e}_{\text{heat}} = ((\% \text{Oil}_{\text{SH}} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP}_{\text{SH}} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG}_{\text{SH}} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec}_{\text{SH}} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood}_{\text{SH}} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

⁵¹ Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70.

⁵² Efficiencies based on 10 CFR 431.110(a), Table 1: Commercial Water Heater Energy Conservation Standards. Weighted using water heater system type mix from Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 67. Assumed tankless coil efficiency of 0.55 per engineering judgement.

$\%Oil_{SH}$, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 23)⁵³

$\eta_{ave,oil}$, etc. = Average heating efficiency for each fuel type [dimensionless] (see Table 23)⁵⁴

Table 23. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Space Heating Fuel | $\%Fuel_{sh}$ | Average Space Heating Efficiency ($\eta_{ave,fuel}$) |
|--------------------|---------------|--|
| Oil | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural Gas | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$\Delta E_{hl} = \text{Space heating load change} = -(Q_{load} \times IF_{heat}) / CCE_{HPWH}$$

IF_{heat} = Interactive factor, portion of HPWH ambient cooling impact that results in increased space heating = 0.542.⁵⁵

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{cool} = \text{Space cooling impacts [g]} = (\Delta E_{cl} \times C_{elec}) / \eta_{cool} / (1 - TD_{elec})$$

$$\eta_{cool} = \text{Assumed cooling system COP} = 3.52.⁵⁶$$

$$\Delta E_{cl} = \text{Change in cooling load [MJ]} = (Q_{load} \times IF_{cool}) / CCE_{HPWH}$$

IF_{cool} = Interactive factor, portion of HPWH ambient cooling impact that results in decreased space cooling = 0.188⁵⁷

$\%Cool$ = Presence of existing cooling⁵⁸

⁵³ Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70.

⁵⁴ Derived from Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Table 17 and Figure 50. Wood boiler efficiency of 0.75 assumed per Efficiency Vermont TRM Program Year 2023, Central Wood Pellet Boilers and Furnaces.

⁵⁵ 2023 Vermont Tier III TRM, HPWH. “Based on bin analysis of annual heating hours for Burlington, VT using TMY3 data: 4484 / 8760 = 51.2%. Tier III trm-analysis-res-hpwh-nea-spec-2021.xlsx.”

⁵⁶ Because of the large diversity of cooling types in C/I buildings, it is difficult to estimate the average efficiency. Accordingly, a coefficient of performance (COP) of 3.52 is assumed, equivalent to 1 kW/ton and 12 SEER.

⁵⁷ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. “Based on bin analysis of annual cooling hours for Burlington, VT using TMY3 data: 1650/8760 = 18.8%, see “2023 Clothes Dryer Analysis.xlsx””

⁵⁸ Derived from US Energy Information Administration Commercial Buildings Energy Consumption Survey (CBECS) 2018, Table B21, New England.

Table 24. Percentage of C/I Customers with Cooling

| Air Conditioning? | %Cool |
|-------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

Common Inputs

$$Q_{load} = \text{Annual water heating load [MJ]} = (8.33 \times (T_{set} - T_{inlet}) \times \text{GPD/unit} \times 365) \times 0.00106$$

8.33 = Specific heat of water; energy required to heat one gallon of water by one degree Fahrenheit [Btu/(gal-°F)]

T_{set} = Hot water temperature setpoint [°F]. From application or assume 140°F.⁵⁹

T_{inlet} = Inlet water temperature of water entering the facility = 51.8°F.⁶⁰

GPD/unit = Average gallons per day of domestic hot water delivered by baseline water heater over one year. From application or estimate from Table 25⁶¹ using rate if facility size in square feet (SF) is known, or use default GPD. Note: GPD figures represent total DHW consumption for the facility. A facility may have multiple water heaters. GPD/unit is the estimated DHW consumed by the baseline water heater to be replaced with the HPWH.

365 = Days per year.

0.00106 = MJ per Btu.

Table 25. Assumed Domestic Hot Water Consumption by Building Type

| Building Type | Default GPD | Rate | Notes/Assumptions | Source |
|----------------------|-------------|------------------------|-----------------------------------|--|
| Assembly | 239 | 7.02 GPD per 1,000 SF | Assumes 10% hot water, 34,000 SF | EIA ⁶² : Public Assembly |
| Auto Repair | 25 | 4.89 GPD per 1,000 SF | Assumes 10% hot water, 5,150 SF | EIA: Other |
| Big Box Retail | 448 | 3.43 GPD per 1,000 SF | Assumes 10% hot water, 130,500 SF | EIA: Mercantile |
| Community College | 1520 | 1.9 GPD per person | Assumes 800 students | NREL ⁶³ : School with Showers |
| Dormitory | 8600 | 17.2 GPD per resident | Assumes 500 residents | Water Research Foundation ⁶⁴ |
| Elementary School | 250 | 0.5 GPD per student | Assumes 500 students | NREL: School |
| Fast Food Restaurant | 500 | 500 GPD per restaurant | | FSTC ⁶⁵ : Quick Service |

⁵⁹ New York TRM v11. “Per OSHA recommendations for prevention of Legionella bacterial growth. (https://www.osha.gov/SLTC/legionnairesdisease/control_prevention.html)”

⁶⁰ Efficiency Vermont Technical Reference Manual. 2023. Average value for Burlington, Montpelier, Rutland, and Springfield, VT from U.S. DOE Standard Building America DHW Schedules, May 2014. Values found on Weather Inputs sheet on spreadsheet. <http://energy.gov/eere/buildings/downloads/building-america-standard-dhw-schedules>

⁶¹ New York TRM v11, C/I Storage Tank Water Heater.

⁶² U.S. Energy Information Administration, 2012 Commercial Buildings Energy Consumption Survey: Water Consumption in Large Buildings, Table WD1. Daily water consumption in large commercial buildings, 2012.

⁶³ National Renewable Energy Laboratory, Saving Energy in Commercial Buildings: Domestic Hot Water Assessment Guidelines, Table 1. Hot Water Use By Building Type, June 2011.

⁶⁴ Water Research Foundation: Residential End Uses of Water, Version 2, April 2016.

⁶⁵ Food Service Technology Center, Design Guide – Energy Efficient Heating, Delivery and Use, Table 1. Typical hot water system cost for restaurants, March 2010.

| Building Type | Default GPD | Rate | Notes/Assumptions | Source |
|-------------------------|-------------|--------------------------|-----------------------------------|------------------------------------|
| Full-Service Restaurant | 2500 | 2,500 GPD per restaurant | | FSTC: Full Service |
| Grocery | 172 | 3.43 GPD per 1,000 SF | Assumes 10% hot water, 50,000 SF | EIA: Mercantile |
| High School | 1520 | 1.9 GPD per person | Assumes 800 students | NREL: School with Showers |
| Hospital | 16938 | 54.42 GPD per 1,000 SF | Assumes 40% hot water, 250,000 SF | EIA: Health Care, Inpatient |
| Hotel | 9104 | 45.52 GPD per 1,000 SF | Assumes 40% hot water, 200,000 SF | EIA: Lodging |
| Large Office | 550 | 1.1 GPD per person | Assumes 500 people | NREL: Office |
| Large Retail | 446 | 3.43 GPD per 1,000 SF | Assumes 10% hot water, 130,000 SF | EIA: Mercantile |
| Light Industrial | 489 | 4.89 GPD per 1,000 SF | Assumes 10% hot water, 100,000 SF | EIA: Other |
| Motel | 1366 | 45.52 GPD per 1,000 SF | Assumes 40% hot water, 30,000 SF | EIA: Lodging |
| Multifamily High-Rise | 3440 | 34.4 GPD per unit | Assumes 100 units | NY MF Baseline Study ⁶⁶ |
| Multifamily Low-Rise | 413 | 34.4 GPD per unit | Assumes 12 units | NY MF Baseline Study |
| Refrigerated Warehouse | 86 | 0.93 GPD per 1,000 SF | Assumes 10% hot water, 92,000 SF | EIA: Warehouse and Storage |
| Religious | 77 | 7.02 GPD per 1,000 SF | Assumes 10% hot water, 11,000 SF | EIA: Public Assembly |
| Small Office | 110 | 1.1 GPD per person | Assumes 100 people | NREL: Office |
| Small Retail | 27 | 3.43 GPD per 1,000 SF | Assumes 10% hot water, 8,000 SF | EIA: Mercantile |
| University | 1000 | 0.5 GPD per student | Assumes 2,000 students | NREL: School |
| Warehouse | 465 | 0.93 GPD per 1,000 SF | Assumes 10% hot water, 500,000 SF | EIA: Warehouse and Storage |
| Other | Calculate | 4.89 GPD per 1,000 SF | Assumes 10% hot water | EIA: Other |

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 12 years.⁶⁷

MEASURE COST

Installed cost estimates have not been identified for this measure.

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- SysCOP of proposed heat pump water heater or Tier
- Fuel source of existing water heater

For increased accuracy, the following variable may optionally be tracked:

⁶⁶ Residential Statewide Baseline Study of New York State, July 2015. Volume 2: Multifamily Report, Table 8.

⁶⁷ Efficiency Vermont TRM Program Year 2023, HPWH. "NREL, National Residential Efficiency Measure Database Lifetime of Heat Pump measures. Please see files in Referenced Documents. Current link: <https://remdb.nrel.gov/measures.php?glid=6&ctid=270>"

- Existing space heating system fuel
- Existing A/C presence

ENERGY CODES AND STANDARDS

Minimum efficiencies for commercial water heaters are prescribed in 10 CFR 431.110(a).

Heat pump water heaters must conform to the NEEA Advanced Water Heating Specification for Commercial/Multifamily Heat Pump Water Heaters to use this characterization.

2.3.2 LOW FLOW FAUCET AERATOR

CHS Measure ID: CI_DOHW_LFFA

Market Sector: Commercial/Industrial

End Use: Domestic Hot Water

Applicable Building Types: Non-Residential

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Grid Electricity

Decision/Action Type: Retrofit, MOP: New Construction

Program Delivery Type: Direct Install, New Construction, Free Products, Dropship

MEASURE DESCRIPTION

This measure relates to the installation of low flow faucet aerators in commercial and industrial buildings. Low flow aerators reduce the volume of hot water consumed and thus the thermal energy needed to heat it.

This measure may be installed through one of the following mechanisms:

- Commercial new construction program
- Direct install implementation
- Free giveaways
- Dropship: product is ordered by building owner or implementer and drop-shipped to the site for self-installation. The program delivery agent shall verify the installation with the owner and reserve the right to inspect the installation.

Baseline Conditions

Retrofit: Existing bath or kitchen faucet aerator rated at 2.2 GPM.⁶⁸

New Construction: New standard flow rate faucet aerator rated at 1.5 GPM.⁶⁹

Additionally, two options are presented for the existing water heater fuel impacts:

1. A hypothetical water heater consuming a representative mix of oil, natural gas, propane, and electricity is assumed. This option is suitable for free giveaways.
2. Water heater fuel impacts are calculated based on the actual water heater fuel. This option is suitable for direct install, new construction and dropship implementations.

Proposed Conditions

Direct Install, Giveaways, and Dropship: Faucet aerator rated at 1.0 GPM for bathroom faucets and 1.5 GPM for kitchen faucets.

⁶⁸ Existing faucets are assumed to comply with the federal standard which is 2.2 GPM at 60 psi. 10 CFR § 430.32.

⁶⁹ New construction faucets are assumed to comply with the Vermont state standard for faucets which is 1.5 GPM at 60 psi. 9 V.S.A. § 2795.14. The Vermont standard took effect on 7/1/2020.

New Construction: Faucet aerator rated at 1.3 GPM ⁷⁰

ELIGIBILITY CRITERIA

For Direct Install, Free Products, and Dropship programs, the qualifying efficient flow rate for faucet aerators must be 1.0 GPM for bathroom and 1.5 GPM for kitchen. For New Construction, the aerator must be WaterSense-labeled (<https://www.epa.gov/watersense>).

DECARBONIZATION SUMMARY

Table 26 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Average water heating fuel mix in Table 27
- Water heater efficiencies per Table 27
- Unknown building type

Table 26. Example Lifetime Faucet Aerator CO₂e Reductions

| Program Delivery Type | Faucet Type | Baseline Aerator | Proposed Aerator | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------------|-------------|------------------|------------------|---|--|------------------|
| Direct Install | Kitchen | 2.2 GPM | 1.5 GPM | 382,884 | 382,884 | 0.3829 |
| | Bath | 2.2 GPM | 1.0 GPM | 694,313 | 694,313 | 0.6943 |
| New Construction | Kitchen | 1.5 GPM | 1.3 GPM | 9,548 | 9,548 | 0.0095 |
| | Bath | 1.5 GPM | 1.3 GPM | 7,926 | 7,926 | 0.0079 |
| Free Products | Kitchen | 2.2 GPM | 1.5 GPM | 237,388 | 237,388 | 0.2374 |
| | Bath | 2.2 GPM | 1.0 GPM | 430,474 | 430,474 | 0.4305 |
| Dropship | Kitchen | 2.2 GPM | 1.5 GPM | 344,595 | 344,595 | 0.3446 |
| | Bath | 2.2 GPM | 1.0 GPM | 624,882 | 624,882 | 0.6249 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector Decarbonization Impacts:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

⁷⁰ Efficiency Vermont Technical Reference Manual. 2023. Average flow rate of products on the WaterSense Labeled Products list as of October 18, 2022.

CreditValue = 1 credit/tonneCO2e

1,000,000 = Grams per metric ton.

$\Delta\text{CO2e}_{\text{direct}}$ = Annual CO2e reduction [g] due to equipment replacement

If water heater fuel is known:

$$\text{Oil: } \Delta\text{CO2e}_{\text{direct}} = (\Delta E_{\text{whl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{RE}_{\text{oil}}$$

$$\text{Propane: } \Delta\text{CO2e}_{\text{direct}} = (\Delta E_{\text{whl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{RE}_{\text{LP}}$$

$$\text{Natural Gas: } \Delta\text{CO2e}_{\text{direct}} = ((\Delta E_{\text{whl}} \times \text{CI}_{\text{NG}}) / \text{RE}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Electricity: } \Delta\text{CO2e}_{\text{direct}} = ((\Delta E_{\text{whl}} \times \text{CI}_{\text{elec}}) / \text{RE}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

If water heater fuel is unknown:

$$\Delta\text{CO2e} = (\% \text{Oil} \times \Delta E_{\text{whl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{RE}_{\text{oil}} + (\% \text{LP} \times \Delta E_{\text{whl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \text{RE}_{\text{LP}} + (\% \text{NG} \times \Delta E_{\text{whl}} \times \text{CI}_{\text{NG}}) / \text{RE}_{\text{NG}} / (1 - \text{TDL}_{\text{NG}}) + (\% \text{Elec} \times \Delta E_{\text{whl}} \times \text{CI}_{\text{elec}}) / \text{RE}_{\text{elec}} / (1 - \text{TDL}_{\text{elec}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's water heating fuel mix (see Table 27)⁷¹

RE_{oil} etc. = Average water heater recovery efficiency by fuel type (see

Table 27)⁷²

Table 27. Vermont Water Heating Fuel Mix and Average Recovery Efficiency, C/I Buildings

| Water Heating Fuel | %Fuel | Recovery Efficiency (RE _{fuel}) |
|--------------------|-------|---|
| Oil | 11% | 0.83 |
| Propane (LP) | 32% | 0.83 |
| Natural Gas | 15% | 0.83 |
| Electricity | 42% | 1.71 |

ΔE_{whl} = Reduction in water heating load [MJ] = (GPM_{Base} x Throttle_{Base} - GPM_{Low} x Throttle_{Low}) x 60 x (Hrs/Day) x (Days/Year) x 8.3 x (T_{Faucet} - T_{inlet}) x ISR x 0.00106

GPM_{Base} = Flow rate of existing faucet aerator = 2.2 GPM for retrofit; 1.5 GPM for new construction

GPM_{Low} = Flow rate of low flow faucet aerator

= 1.3 GPM for New Construction

⁷¹ Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70.

⁷² Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 5, 6, 18, and 19.

= 1.0 GPM (bathroom) and 1.5 GPM (kitchen) for Direct Install, Free Products and Dropship

Throttle_{Base} = Percentage of full-throttle flow rate for baseline faucet = 83% ⁷³

Throttle_{Low} = Percentage of full-throttle flow rate for low flow faucet = 95% ⁷⁴

Hours/Day = Hours per day the faucet is used = 0.25 ⁷⁵

Days/Year = Operating days per year, based on facility type.⁷⁶

Table 28. Operating Days per Year by Facility Type

| Facility Type | Days/Year |
|-----------------------|-----------|
| Community College | 283 |
| Fast Food | 363 |
| Full Restaurant | 321 |
| Grocery | 365 |
| Hospital | 365 |
| Hotel | 365 |
| Miscellaneous | 365 |
| Primary School | 180 |
| Secondary School | 180 |
| Small Office | 250 |
| University | 283 |
| Unknown ⁷⁷ | 302 |

T_{Faucet} = Mixed water temperature (°F) of hot water coming from faucet = 86 °F (bathroom); 93 °F (kitchen)⁷⁸

T_{inlet} = Inlet water temperature (°F) of water entering the household = 51.8 °F⁷⁹

ISR = In-service rate, the percentage of incentivized units actually installed ⁸⁰

⁷³ Efficiency Vermont Technical Reference Manual. 2023. Schultdt, Marc, and Debra Tachibana, "Energy Related Water Fixture Measurements: Securing the Baseline for Northwest Single Family Homes. 2008 ACEEE Summer Study on Energy Efficiency in Buildings," 2008, page 1-265.

⁷⁴ Ibid.

⁷⁵ FEMP, Domestic Water Conservation Technologies, p. 35.

⁷⁶ California Energy Commission, Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment, Appendix E.

⁷⁷ The Unknown building type value is equal to the average of the known building type values.

⁷⁸ Ibid.

⁷⁹ Efficiency Vermont Technical Reference Manual. 2023. Average value for Burlington, Montpelier, Rutland, and Springfield, VT from U.S. DOE Standard Building America DHW Schedules, May 2014. Values found on Weather Inputs sheet on spreadsheet.

<http://energy.gov/eere/buildings/downloads/building-america-standard-dhw-schedules>

⁸⁰ Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 12, 13.

Table 29. Low Flow Faucet Aerator ISRs

| Delivery Type Product | ISR |
|-----------------------|------|
| Direct Install | 100% |
| New Construction | 100% |
| Free Products | 62% |
| Dropship | 90% |

8.3 = Specific heat of water, the amount of energy needed to raise 1 gal of water by 1 °F [BTU/(gal °F)]

0.00106 = MJ per BTU

60 = Minutes per hour

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

Non-Thermal Sector CO₂e Impacts: None

Common Inputs:

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life of installed equipment is estimated to be 10 years.⁸¹

MEASURE COST

Direct Install: Combined labor and material costs. Default is \$13 if actual is unknown.

New Construction: Incremental material cost is \$6.

Free Products and Dropship: The measure cost for free giveaways and the dropship program is the actual program cost of a new aerator. Default = \$2 if actual is unknown.⁸²

⁸¹ Efficiency Vermont Technical Reference Manual. 2023. Measure lifetime from California DEER. See file DEER2014-EUL-table-update_2014-02-05.xlsx.

⁸² Efficiency Vermont Technical Reference Manual. 2023. See footnotes 21-23.

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

Direct Install, New Construction, Dropship:

- Aerator flow: 1.0, 1.3, or 1.5 GPM (GPM_{Low})
- Water heater fuel
- Building type

Free Giveaways:

- Aerator flow: 1.0, 1.3, or 1.5 GPM (GPM_{Low})

ENERGY CODES AND STANDARDS

The baseline assumption for new construction is assumed to be the state standard which took effect on 7/1/2020⁸³.

- 9 V.S.A. § 2795.14: maximum faucet flow rate is 1.5 GPM at 60 psi

The baseline assumption for existing buildings is assumed to be the federal standard.

- 10 CFR § 430.32: maximum faucet flow rate is 2.2 GPM at 60 psi

For New Construction, the installed aerator must meet the US EPA's WaterSense criteria.

⁸³ "Vermont 2018". Appliance Standards Awareness Project, <https://appliance-standards.org/state-legislation/vermont-2018>.

2.3.3 LOW FLOW SHOWERHEAD

CHS Measure ID: CI_DOHW_LFSH

Market Sector: Commercial

End Use: Domestic Hot Water

Applicable Building Types: Commercial and Industrial

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Grid Electricity

Decision/Action Type: Early Replacement, MOP: New Construction

Program Delivery Type: Direct Install, New Construction, Dropship

MEASURE DESCRIPTION

This measure relates to the installation of low flow showerheads in commercial and industrial buildings. Low flow showerheads reduce the volume of hot water consumed and thus the thermal energy needed to heat it.

This measure may be installed through one of the following mechanisms:

- Direct install implementation
- C/I new construction program
- Dropship: product is ordered by building owner or implementer and drop-shipped to the site for self-installation. The program delivery agent shall verify the installation with the owner and reserve the right to inspect the installation.

Baseline Conditions

Early Replacement: Existing showerhead rated at 2.5 GPM.⁸⁴

New Construction: New standard flow rate showerhead rated at 2.0 GPM.⁸⁵

Proposed Conditions

Direct Install and Dropship: Low flow showerhead rated at 1.5 GPM.⁸⁶

New Construction: Showerhead rated at 1.8 GPM.⁸⁷

ELIGIBILITY CRITERIA

The qualifying efficient flow rate for showerheads is 1.5 GPM for Direct Install, Free Products, and Dropship programs. For New Construction, the showerhead must be WaterSense-labeled (<https://www.epa.gov/watersense>).

⁸⁴ Existing showerheads are assumed to comply with the federal standard which is 2.5 GPM at 80 psi. 10 CFR § 430.32

⁸⁵ New construction showerheads are assumed to comply with the Vermont state standard for faucets which is 2.0 GPM at 80 psi. 9 V.S.A. § 2795.14. The Vermont standard took effect on 7/1/2020.

⁸⁶ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnote 10

⁸⁷ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnote 11

DECARBONIZATION SUMMARY

Table 30 provides example lifecycle CO₂e reductions for eligible existing and proposed conditions over the expected useful life of the measure. This is a partially deemed measure; actual reductions will depend on the Uses/Day input collected from applications. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Average water heating fuel mix in Table 31
- Water heater efficiencies per Table 31
- One shower taken per day for 365 days per year (example only, not a deemed parameter)

Table 30. Example C/I Low Flow Showerhead CO₂e Reductions

| Program Delivery Type | Baseline Showerhead | Proposed Showerhead | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------------|---------------------|---------------------|---|--|------------------|
| Direct Install | 2.5 GPM | 1.5 GPM | 716,605 | 716,605 | 0.7166 |
| New Construction | 2.0 GPM | 1.8 GPM | 143,321 | 143,321 | 0.1433 |
| Free Products | 2.5 GPM | 1.5 GPM | 401,299 | 401,299 | 0.4013 |
| Dropship | 2.5 GPM | 1.5 GPM | 644,944 | 644,944 | 0.6449 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g]} \text{ due to equipment replacement}$$

If water heater fuel is known:

$$\text{Oil: } \Delta\text{CO}_2\text{e}_{\text{direct}} = (\Delta E_{\text{whl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / RE_{\text{oil}}$$

$$\text{Propane: } \Delta\text{CO}_2\text{e}_{\text{direct}} = (\Delta E_{\text{whl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / RE_{\text{LP}}$$

$$\text{Natural Gas: } \Delta\text{CO}_2\text{e}_{\text{direct}} = ((\Delta E_{\text{whl}} \times CI_{\text{NG}}) / RE_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Electricity: } \Delta\text{CO}_2\text{e}_{\text{direct}} = ((\Delta E_{\text{whl}} \times CI_{\text{elec}}) / RE_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

If water heater fuel is unknown:

$$\Delta\text{CO}_2\text{e} = (\% \text{Oil} \times \Delta E_{\text{whl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{RE}_{\text{oil}} + (\% \text{LP} \times \Delta E_{\text{whl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \text{RE}_{\text{LP}} + (\% \text{NG} \times \Delta E_{\text{whl}} \times \text{CI}_{\text{NG}}) / \text{RE}_{\text{NG}} / (1 - \text{TDL}_{\text{NG}}) + (\% \text{Elec} \times \Delta E_{\text{whl}} \times \text{CI}_{\text{elec}}) / \text{RE}_{\text{elec}} / (1 - \text{TDL}_{\text{elec}})$$

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 34)⁸⁸

RE_{oil} etc. = Average water heater recovery efficiency by fuel type (see Table 31)⁸⁹

Table 31. Vermont Water Heating Fuel Mix and Average Recovery Efficiency, C/I Buildings

| Water Heating Fuel | %Fuel | Recovery Efficiency (RE _{fuel}) |
|--------------------|-------|---|
| Oil | 11% | 0.83 |
| Propane (LP) | 32% | 0.83 |
| Natural Gas | 15% | 0.83 |
| Electricity | 42% | 1.71 |

ΔE_{whl} = Reduction in water heating load [MJ]

$$= ((\text{GPM}_{\text{Base}} - \text{GPM}_{\text{Low}}) \times (\text{Minutes/Use}) \times (\text{Uses/Day}) \times (\text{Days/Year}) / 8.3 \times (\text{T}_{\text{Sh}} - \text{T}_{\text{inlet}}) / \eta_{\text{RE}} \times \text{ISR} \times 0.00106$$

GPM_{Base} = Flow rate of existing showerhead = 2.5 GPM for Retrofits, 2.0 GPM for New Construction.

GPM_{Low} = Flow rate of low flow showerhead = 1.5 GPM for Retrofits; 1.8 GPM for new construction

Minutes/Shower = Average shower length in minutes per person = 7.8⁹⁰

Uses/Day = Estimated number of showers taken per day for one showerhead; collected from application

Days/Year = Days the showerhead is used per year = 365

T_{Sh} = Mixed water temperature (°F) of hot water coming from showerhead = 101°F⁹¹

T_{inlet} = Inlet water temperature (°F) of water entering the building = 51.8°F⁹²

ISR = In-service rate, the percentage of incentivized units actually installed⁹³

Table 32. Low Flow Showerhead ISRs

| Product Delivery Type | ISR |
|-----------------------|-----|
|-----------------------|-----|

⁸⁸ Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70.

⁸⁹ Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 5, 6, 18, and 19.

⁹⁰ Cadmus and Opinion Dynamics, for the Michigan Evaluation Working Group, "Showerhead and Faucet Aerator Meter Study Memorandum," June 2013, page 11, Table 7.

⁹¹ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 16

⁹² Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 17

⁹³ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnotes 12, 13.

| | |
|------------------|------|
| Direct Install | 100% |
| New Construction | 100% |
| Free Products | 56% |
| Dropship | 90% |

8.3 = Specific heat of water, the amount of energy needed to raise 1 gal of water by 1 °F [BTU/(gal °F)]

0.00106 =BTU per MJ

Non-Thermal Sector CO2e Impacts: None

Common Inputs:

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life of installed equipment is estimated to be 10 years.⁹⁴

MEASURE COST

Direct Install: Combined labor and material costs. Default is \$22 for a fixed showerhead and \$27 for a handheld model.

New Construction: Incremental material cost is \$6.

Free Products and Dropship: The measure cost for free giveaways and the dropship program is the actual program cost of a new showerhead. Default = \$4 if unknown.⁹⁵

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

Direct Install, New Construction, Dropship:

- Showerhead flow: 1.5 GPM or 1.8 GPM (GPM_{Low})
- Water heater fuel
- Number of showers per day per showerhead

ENERGY CODES AND STANDARDS

⁹⁴ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 21

⁹⁵ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 198. See footnotes 22 – 25.

The baseline assumption for new construction is assumed to be the state standard which took effect on 7/1/2020⁹⁶.

- 9 V.S.A. § 2795.14: maximum shower flow rate is 2.0 GPM at 80 psi

The baseline assumption for existing buildings is assumed to be the federal standard.

- 10 CFR § 430.32: maximum shower flow rate is 2.5 GPM at 80 psi

For New Construction, the installed showerhead must meet the US EPA's WaterSense criteria.

⁹⁶ "Vermont 2018". Appliance Standards Awareness Project, <https://appliance-standards.org/state-legislation/vermont-2018>.

2.3.4 SOLAR WATER HEATER

CHS Measure ID: CI_DOHW_SOWH

Market Sector: Commercial/Industrial

End Use: Domestic Hot Water

Applicable Building Types: Non-Residential, Multifamily

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Fuel Oil #2, Natural Gas, Propane, Electricity

Decision/Action Type: MOP. Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of a solar water heater serving a C/I facility or multiple dwelling units in a multifamily building. These products use solar energy to heat domestic water directly, or indirectly via a non-freezing heat transfer fluid. The latter type is best suited for northern climates. Solar water heaters include a solar collector and storage tank with electric or fossil fuel backup heating.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical conventional water heater consuming a representative mix of oil, natural gas, propane, and electricity. This scenario is suitable for Downstream offerings in which the baseline water heater fuel is not collected.
2. A minimum efficiency oil, natural gas, propane, or electric water heater. This scenario is suitable for Downstream offerings in which the baseline water heater fuel is collected.

Proposed Conditions

The proposed condition is a solar water heater installation including a solar collector and storage tank with electric or fossil fuel backup heating.

ELIGIBILITY CRITERIA

The solar water heater must be OG-300 certified by the Solar Rating & Certification Corporation (ICC-SRCC).⁹⁷

DECARBONIZATION SUMMARY

Table 33 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

⁹⁷ See <https://solar-rating.org> for certified product list.

Assumptions:

- Baseline and backup water heater fuels are the same
- Baseline water heater efficiency by fuel per Table 34
- Small office building, 110 gallons of DHW consumed daily

Table 33. Example C/I Solar Water Heater CO₂e Reductions

| Backup Fuel | SUEF Range | Assumed SUEF | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-------------|----------------|--------------|---|--|------------------|
| Oil | 1.0 to < 1.5 | 1.25 | 23,420,192 | 23,420,192 | 23.4 |
| | 1.5 to < 2.0 | 1.75 | 35,316,162 | 35,316,162 | 35.3 |
| | 2 to < 2.5 | 2.25 | 41,925,035 | 41,925,035 | 41.9 |
| | 2.5 or greater | 3.00 | 47,707,798 | 47,707,798 | 47.7 |
| Natural Gas | 1.0 to < 1.5 | 1.25 | 18,169,590 | 18,169,590 | 18.2 |
| | 1.5 to < 2.0 | 1.75 | 27,398,588 | 27,398,588 | 27.4 |
| | 2 to < 2.5 | 2.25 | 32,525,809 | 32,525,809 | 32.5 |
| | 2.5 or greater | 3.00 | 37,012,128 | 37,012,128 | 37.0 |
| Propane | 1.0 to < 1.5 | 1.25 | 20,709,352 | 20,709,352 | 20.7 |
| | 1.5 to < 2.0 | 1.75 | 31,228,389 | 31,228,389 | 31.2 |
| | 2 to < 2.5 | 2.25 | 37,072,298 | 37,072,298 | 37.1 |
| | 2.5 or greater | 3.00 | 42,185,718 | 42,185,718 | 42.2 |
| Electricity | 1.0 to < 1.5 | 1.25 | 5,788,540 | 5,788,540 | 5.8 |
| | 1.5 to < 2.0 | 1.75 | 8,728,751 | 8,728,751 | 8.7 |
| | 2 to < 2.5 | 2.25 | 10,362,201 | 10,362,201 | 10.4 |
| | 2.5 or greater | 3.00 | 11,791,470 | 11,791,470 | 11.8 |
| Unknown | 1.0 to < 1.5 | 1.25 | 14,359,839 | 14,359,839 | 14.4 |
| | 1.5 to < 2.0 | 1.75 | 21,653,726 | 21,653,726 | 21.7 |
| | 2 to < 2.5 | 2.25 | 25,705,885 | 25,705,885 | 25.7 |
| | 2.5 or greater | 3.00 | 29,251,524 | 29,251,524 | 29.3 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g] due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{swh}}$$

$CO2e_{base}$ = Annual CO2e emissions [g] from baseline water heater

If baseline water heater fuel is known:

Oil: $CO2e_{base} = (Q_{load} \times (CI_{oil} + CI'_{oil}) / EF_{min})$

Propane: $CO2e_{base} = (Q_{load} \times (CI_{LP} + CI'_{LP}) / EF_{min})$

Natural Gas: $CO2e_{base} = (Q_{load} / EF_{min} \times CI_{NG}) / (1 - TDL_{NG})$

Electricity: $CO2e_{base} = (Q_{load} / EF_{min} \times CI_{elec}) / (1 - TDL_{elec})$

If baseline water heater fuel is unknown:

$CO2e_{base} = ((\%Oil_{WH} \times Q_{load} \times (CI_{oil} + CI'_{oil})) / EF_{min}) + ((\%LP_{WH} \times Q_{load} \times (CI_{LP} + CI'_{LP})) / EF_{min}) + ((\%NG_{WH} \times Q_{load} \times CI_{NG}) / EF_{min}) / (1 - TDL_{NG}) + ((\%EleC_{WH} \times Q_{load} \times CI_{elec}) / EF_{min}) / (1 - TDL_{elec})$

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 34)⁹⁸

EF_{min} = Minimum water heater efficiency [dimensionless] by fuel. Based on CFR minimum efficiency requirements for commercial water heating equipment. See Table 34.⁹⁹

Table 34. Vermont Water Heating Fuel Mix and Minimum Heating Efficiency, C/I Buildings

| Water Heating Fuel | %Fuel _{wh} | Minimum Water Heater Efficiency (EF _{min}) |
|--------------------|---------------------|--|
| Oil | 11% | 0.80 |
| Propane (LP) | 32% | |
| Natural Gas (NG) | 15% | |
| Electricity | 42% | |

$CO2e_{swh}$ = Annual CO2e emissions [g] from solar water heater

If backup water heater fuel is known:

Oil: $CO2e_{swh} = (Q_{load} \times (CI_{oil} + CI'_{oil}) / SUEF)$

Propane: $CO2e_{swh} = (Q_{load} \times (CI_{LP} + CI'_{LP}) / SUEF)$

Natural Gas: $CO2e_{swh} = (Q_{load} / SUEF \times CI_{NG}) / (1 - TDL_{NG})$

Electricity: $CO2e_{swh} = (Q_{load} / SUEF \times CI_{elec}) / (1 - TDL_{elec})$

If backup water heater fuel is unknown:

⁹⁸ Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70.

⁹⁹ 10 CFR 431.110(a). Table 1: Commercial Water Heater Energy Conservation Standards.

$$CO2_{eSWH} = ((\%Oil \times Q_{load} \times (CI_{oil} + CI'_{oil}))/SUEF) + ((\%LP \times Q_{load} \times (CI_{LP} + CI'_{LP}))/SUEF) + ((\%NG \times Q_{load} \times CI_{NG})/SUEF)/(1-TD_{LNG}) + ((\%Elec \times Q_{load} \times CI_{elec})/SUEF)/(1-TD_{Lelec})$$

SUEF = Solar Uniform Energy Factor rating of the solar water heater [dimensionless], as certified by ICC-SRCC.

Non-Thermal Sector CO2e Impacts: None

Common Inputs

$$Q_{load} = \text{Annual water heating load [MJ]} = (8.33 \times (T_{set} - T_{inlet}) \times \text{GPD/unit} \times 365) \times 0.00106$$

8.33 = Specific heat of water; energy required to heat one gallon of water by one degree Fahrenheit [Btu(gal-°F)]

T_{set} = Hot water temperature setpoint [°F]. From application or assume 140 °F.¹⁰⁰

T_{inlet} = Inlet water temperature of water entering the facility = 51.8 °F.¹⁰¹

GPD/unit = Average gallons per day of domestic hot water delivered by baseline water heater over one year. From application or estimate from Table 35 using rate if facility size in square feet (SF) is known, or use default GPD.¹⁰² Note: GPD figures represent total DHW consumption for the facility. A facility may have multiple water heaters. GPD/unit is the estimated DHW consumed by the baseline water heater to be replaced with the SWH system.

365 = Days per year.

0.00106 = MJ per Btu

Table 35. Assumed Domestic Hot Water Consumption by Building Type

| Building Type | Default GPD | Rate | Notes/Assumptions | Source |
|-------------------|-------------|-----------------------|-----------------------------------|---|
| Assembly | 239 | 7.02 GPD per 1,000 SF | Assumes 10% hot water, 34,000 SF | EIA ¹⁰³ ; Public Assembly |
| Auto Repair | 25 | 4.89 GPD per 1,000 SF | Assumes 10% hot water, 5,150 SF | EIA: Other |
| Big Box Retail | 448 | 3.43 GPD per 1,000 SF | Assumes 10% hot water, 130,500 SF | EIA: Mercantile |
| Community College | 1520 | 1.9 GPD per person | Assumes 800 students | NREL ¹⁰⁴ ; School with Showers |
| Dormitory | 8600 | 17.2 GPD per resident | Assumes 500 residents | Water Research Foundation ¹⁰⁵ |
| Elementary School | 250 | 0.5 GPD per student | Assumes 500 students | NREL: School |

¹⁰⁰ New York TRM v11. “Per OSHA recommendations for prevention of Legionella bacterial growth. (https://www.osha.gov/SLTC/legionnairesdisease/control_prevention.html)”

¹⁰¹ Efficiency Vermont Technical Reference Manual. 2023. Average value for Burlington, Montpelier, Rutland, and Springfield, VT from U.S. DOE Standard Building America DHW Schedules, May 2014. Values found on Weather Inputs sheet on spreadsheet. <http://energy.gov/eere/buildings/downloads/building-america-standard-dhw-schedules>

¹⁰² Table 6 is from New York TRM v11, C/I Storage Tank Water Heater.

¹⁰³ U.S. Energy Information Administration, 2012 Commercial Buildings Energy Consumption Survey: Water Consumption in Large Buildings, Table WD1. Daily water consumption in large commercial buildings, 2012.

¹⁰⁴ National Renewable Energy Laboratory, Saving Energy in Commercial Buildings: Domestic Hot Water Assessment Guidelines, Table 1. Hot Water Use By Building Type, June 2011.

¹⁰⁵ Water Research Foundation: Residential End Uses of Water, Version 2, April 2016.

| Building Type | Default GPD | Rate | Notes/Assumptions | Source |
|-------------------------|-------------|--------------------------|-----------------------------------|-------------------------------------|
| Fast Food Restaurant | 500 | 500 GPD per restaurant | | FSTC ¹⁰⁶ : Quick Service |
| Full-Service Restaurant | 2500 | 2,500 GPD per restaurant | | FSTC: Full Service |
| Grocery | 172 | 3.43 GPD per 1,000 SF | Assumes 10% hot water, 50,000 SF | EIA: Mercantile |
| High School | 1520 | 1.9 GPD per person | Assumes 800 students | NREL: School with Showers |
| Hospital | 16938 | 54.42 GPD per 1,000 SF | Assumes 40% hot water, 250,000 SF | EIA: Health Care, Inpatient |
| Hotel | 9104 | 45.52 GPD per 1,000 SF | Assumes 40% hot water, 200,000 SF | EIA: Lodging |
| Large Office | 550 | 1.1 GPD per person | Assumes 500 people | NREL: Office |
| Large Retail | 446 | 3.43 GPD per 1,000 SF | Assumes 10% hot water, 130,000 SF | EIA: Mercantile |
| Light Industrial | 489 | 4.89 GPD per 1,000 SF | Assumes 10% hot water, 100,000 SF | EIA: Other |
| Motel | 1366 | 45.52 GPD per 1,000 SF | Assumes 40% hot water, 30,000 SF | EIA: Lodging |
| Multifamily High-Rise | 3440 | 34.4 GPD per unit | Assumes 100 units | NY MF Baseline Study ¹⁰⁷ |
| Multifamily Low-Rise | 413 | 34.4 GPD per unit | Assumes 12 units | NY MF Baseline Study |
| Refrigerated Warehouse | 86 | 0.93 GPD per 1,000 SF | Assumes 10% hot water, 92,000 SF | EIA: Warehouse and Storage |
| Religious | 77 | 7.02 GPD per 1,000 SF | Assumes 10% hot water, 11,000 SF | EIA: Public Assembly |
| Small Office | 110 | 1.1 GPD per person | Assumes 100 people | NREL: Office |
| Small Retail | 27 | 3.43 GPD per 1,000 SF | Assumes 10% hot water, 8,000 SF | EIA: Mercantile |
| University | 1000 | 0.5 GPD per student | Assumes 2,000 students | NREL: School |
| Warehouse | 465 | 0.93 GPD per 1,000 SF | Assumes 10% hot water, 500,000 SF | EIA: Warehouse and Storage |
| Other | Calculate | 4.89 GPD per 1,000 SF | Assumes 10% hot water | EIA: Other |

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

20 years¹⁰⁸

MEASURE COST

- Retrofit: Use actual installed cost of SWH if available, or assume \$6,000 for planning purposes.¹⁰⁹
- MOP: Determine incremental cost of SWH compared to a conventional gas or electric storage water heater. Default value is \$4,731.¹¹⁰

¹⁰⁶ Food Service Technology Center, Design Guide – Energy Efficient Heating, Delivery and Use, Table 1. Typical hot water system cost for restaurants, March 2010.

¹⁰⁷ Residential Statewide Baseline Study of New York State, July 2015. Volume 2: Multifamily Report, Table 8.

¹⁰⁸ Act 56 Tier III Planning Tool PY2024_2_13_2024.xlsx.

¹⁰⁹ Installed cost of solar water heater is estimated to be \$6,000, midpoint of \$3,000 - \$9,000 range before tax credits and rebates. Source: <https://homeguide.com/costs/solar-water-heater-cost>, accessed August 9, 2024.

¹¹⁰ Baseline water heater installed cost is estimated to \$2,087 - \$818 = \$1,269. Source: 2023 Efficient Vermont TRM, Heat Pump Water Heaters: “NEEP Emerging Technologies Incremental Cost Study Final Report, Table 3-34, pg 81. (2016). See sheet “NEEP Cost Summary” in the Analysis File. For Original Report see file “NEEP Incremental Cost Study FINAL_061016.pdf”. “ Solar water heater incremental cost = \$6,000 - \$1,269 = \$4,731.

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Solar water heater SUEF rating
- Backup fuel (oil, natural gas, propane, or electricity)
- Baseline water heater fuel (oil, natural gas, propane, or electricity)

ENERGY CODES AND STANDARDS

Eligible equipment must comply with the ICC 901/SRCC 300 standard.

2.4 HVAC

2.4.1 ADVANCED THERMOSTATS

CHS Measure ID: CI_HVAC_ADVT

Market Sector: Commercial/Industrial

End Use: HVAC

Applicable Building Types: Non-Residential, Multifamily Common Areas

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Electricity, Wood

Decision/Action Type: Retrofit, MOP:New Construction

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of an advanced thermostat to control a C/I HVAC system. An advanced thermostat is capable of automatically establishing a schedule of temperature setpoints and automatic variations to better match HVAC system run times to meet occupant comfort requirements, resulting in energy savings. These schedules may be defaults, established through user interaction, and be changed manually at the device or remotely through a web or mobile app. Automatic variations to that schedule could be driven by local sensors and software algorithms, and/or through connectivity to an internet software service. Data triggers to automatic schedule changes might include, for example: occupancy/activity detection, arrival & departure of conditioned spaces, optimization based on historical or population-specific trends, weather data and forecasts.¹¹¹

Baseline Conditions

The baseline for Retrofits is assumed to be a mix of programmable and manual thermostats.

The baseline for New Construction is assumed to be a programmable thermostat.

Proposed Conditions

The proposed condition is an advanced thermostat.

ELIGIBILITY CRITERIA

The criteria for this measure are established by replacement of a manual-only or programmable thermostat, with one that has the default enabled capability—or the capability to automatically—establish a schedule of temperature setpoints according to driving device inputs above and beyond basic time and temperature data of conventional programmable thermostats. This category of products and services is broad and rapidly advancing in regard to their capability, usability, and sophistication, but at a minimum must be capable of two-way

¹¹¹ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats.

communication and exceed the typical performance of manual and conventional programmable thermostats through the automatic or default capabilities described above.¹¹²

This measure must be paired with one of the following system types: gas or oil furnace, combination furnace/central AC, gas or oil fossil-fuel boiler, or central air source or ground source heat pump.

DECARBONIZATION SUMMARY

Table 36 provides example lifecycle CO₂e reductions for this measure across eligible heating fuels and Decision/Action Types over the effective useful life of this measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Existing heat pump presence unknown
- Existing A/C presence unknown
- Heating system input capacity defaults (see Table 39):
 - Retrofit: 53,277 Btu/h
 - New Construction: 33,427

Table 36. Example C/I Advanced Thermostat Lifetime CO₂e Reductions

| Decision/Action Type | Heating Fuel | Lifetime CO ₂ e Reductions, Thermal [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|----------------------|--------------|--|--|------------------|
| Retrofit | Oil | 3,783,499 | 3,845,731 | 3.8 |
| | Propane | 3,339,336 | 3,401,568 | 3.3 |
| | Natural Gas | 2,943,579 | 3,005,812 | 2.9 |
| | Electricity | 2,637,602 | 2,699,835 | 2.6 |
| | Wood | 1,653,883 | 1,716,116 | 1.7 |
| | Unknown | 2,637,602 | 2,699,835 | 2.6 |
| New Construction | Oil | 1,416,807 | 1,467,433 | 1.4 |
| | Propane | 1,250,481 | 1,301,107 | 1.3 |
| | Natural Gas | 1,102,282 | 1,152,908 | 1.1 |
| | Electricity | 987,703 | 1,038,329 | 1.0 |
| | Wood | 619,330 | 669,956 | 0.6 |
| | Unknown | 987,703 | 1,038,329 | 1.0 |

¹¹² Ibid.

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$\Delta\text{CO}_2\text{e}_{\text{thermal}}$ = Total annual carbon dioxide equivalent emissions reductions in grams [g] = $\Delta\text{CO}_2\text{e}_{\text{heat}}$

Annual Clean Heat Credits = $\Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$

CreditValue = 1 credit/tonneCO₂e

1,000,000 = Grams per metric ton

$\Delta\text{CO}_2\text{e}_{\text{heat}}$ = CO₂e emissions reductions from reducing heating energy

If heating fuel is known:

Oil: $\Delta\text{CO}_2\text{e}_{\text{heat}} = \Delta E_{\text{heat}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$

Propane: $\Delta\text{CO}_2\text{e}_{\text{heat}} = \Delta E_{\text{heat}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$

Natural Gas: $\Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{heat}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$

Wood: $\Delta\text{CO}_2\text{e}_{\text{heat}} = \Delta E_{\text{heat}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})$

Electricity: $\Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{heat}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$

If heating fuel is unknown:

$\Delta\text{CO}_2\text{e}_{\text{heat}} = (\% \text{Oil} \times \Delta E_{\text{heat}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) + (\% \text{LP} \times \Delta E_{\text{heat}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) + (\% \text{NG} \times \Delta E_{\text{heat}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}}) + (\% \text{Elec} \times \Delta E_{\text{heat}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}}) + (\% \text{Wood} \times \Delta E_{\text{heat}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}}))$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 37)¹¹³

Table 37. Vermont Primary Heating Fuel Mix, C/I Buildings

| Heating Fuel | %Fuel |
|--------------|-------|
| Oil | 15% |
| Propane | 29% |
| Natural Gas | 22% |
| Electricity | 33% |
| Wood | 1% |

ΔE_{heat} = Heating energy reduction [MJ] = $(\text{EFLH}_{\text{heat}} \times \text{Btu}_{\text{in,heat}} \times \text{SF}_{\text{heat}} \times (1 - \% \text{CHP})) \times 0.00106$

$\text{EFLH}_{\text{heat}}$ = Annual equivalent full load heating hours for heating equipment

¹¹³ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. "Other" fuel category removed.

Table 38. Equivalent Full Load Hours, Heating

| Decision/Action Type | EFLH _{heat} ¹¹⁴ |
|----------------------|-------------------------------------|
| Retrofit | 1062 |
| New Construction | 1062 |

Btuh_{in,heat} = Input Capacity of Heating System in Btu/h controlled by thermostat.

For fossil fuel system, use rated if known, or defaults in Table 39.

For heat pump system, Btuh_{in,heat} = Btuh_{out,heat} / COP_{heat} where Btuh_{out,heat} = rated heating output capacity at 47 °F in Btu/h. Use rated output capacity if known, or defaults in Table 40. COP_{heat} = Heating coefficient of performance (COP) of heat pump = 3.28.¹¹⁵

For wood heater, use defaults in Table 39 or calculate from rated capacity: Btuh_{in,heat} = Btuh_{out,heat} / η_w where η_w = wood heating efficiency. Assume η_w = 65% if unknown.¹¹⁶

Table 39. Input Capacity of Fossil Heating System

| Decision / Action Type | BTU _{in,heat} ¹¹⁷ |
|------------------------|---------------------------------------|
| Early Replacement | 53,277 |
| New Construction | 33,427 |

Table 40. Heating Output Capacity of Heat Pump System

| Decision / Action Type | Btuh _{out,heat} ¹¹⁸ |
|------------------------|---|
| Early Replacement | 53,186 |
| New Construction | 31,683 |

SF_{heat} = Assumed savings factor for total heating energy consumption due to installation of advanced thermostat. See Table 43.

¹¹⁴ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats. “Estimated by following a methodology outlined in the Uniform Methods Project using natural gas billing data provided by Vermont Gas Systems (VGS) for homes that participated in Efficiency Vermont’s Residential New Construction (RNC) program. Since capacity has not been collected through the Home Performance with ENERGY STAR program it was not possible to perform the analysis with a more appropriate data set for this program. For Existing Homes, the RNC data was limited to only those homes with annual gas consumption greater than 25kbtu/sq ft in an attempt to remove the high performance/ low load homes in RNC. See ‘VGS Usage Regression Work_04182017.xls’ for analysis.”

¹¹⁵ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. The mean HSPF of Heat Pump Systems is 11.2.

¹¹⁶ Efficiency Vermont TRM Program Year 2023, Central Wood Pellet Boilers and Furnaces. “Efficiency of existing wood heating systems based on professional judgment.”

¹¹⁷ Calculated using assumptions from Efficiency Vermont TRM Program Year 2023, Advanced Thermostats (Capacity = Gas Heating Consumption × 1,000,000/EFLH_{heat}).

¹¹⁸ Calculated using assumptions from Efficiency Vermont TRM Program Year 2023, Advanced Thermostats (Capacity = Electric Heating Consumption × 3412/EFLH_{heat} × %Controlled × COP).

%CHP = Presence of central air source or ground source heat pump as the primary heating system. This variable is used to account for heat pump manufacturer recommendations to limit temperature setbacks during the heating season. ¹¹⁹

| Central Heat Pump? | %CHP | |
|--------------------|-------------------|------------------|
| | Early Replacement | New Construction |
| Yes | 100% | |
| No | 0% | |
| Unknown | 5% | 19% |

Non-Thermal Sector CO2e Impacts:

$$\Delta\text{CO2e}_{\text{cool}} = (\Delta E_{\text{cool}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cool}} = \text{Cooling energy reduction [MJ]} = \% \text{Cool} \times (\text{EFLH}_{\text{cool}} \times \text{Btuh}_{\text{out,cool}} / \text{COP}_{\text{cool}} \times \text{SF}_{\text{cool}}) \times 0.00106$$

$$\text{Btuh}_{\text{out,cool}} = \text{Output cooling capacity of heat pump or AC [Btu/h]} = 41,400 \text{ }^{120}$$

$$\% \text{Cool} = \text{Percentage of customers with central cooling systems}^{121}$$

Table 41. Percentage of C/I Customers with Cooling

| Air Conditioning? | %Cool |
|-------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

$$\text{EFLH}_{\text{cool}} = \text{Estimate of annual equivalent full load cooling hours for heat pump or air conditioner} = 375. \text{ }^{122}$$

$$\text{COP}_{\text{cool}} = \text{Cooling coefficient of performance for air-conditioner or heat pump}$$

Table 42. Cooling COP

| Decision/Action Type | COP _{cool} |
|----------------------------------|---------------------|
| Early Replacement ¹²³ | 4.10 |
| New Construction ¹²⁴ | 5.04 |

¹¹⁹ Source: Tables 50 and 137, Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study.

¹²⁰ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 152, footnote 10

¹²¹ Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England.

¹²² Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 206, footnote 3

¹²³ Calculated from statewide mean SEER = 14.0 of central air conditioner in VT from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Table 32. Cooling Efficiency of Single-Zone Unitary HVAC Systems. COP = SEER/3.412

¹²⁴ Calculated from statewide mean SEER = 17.2 of central air conditioner in VT from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Table 58. Cooling Efficiency of Single-Zone Unitary HVAC Systems. COP = SEER/3.412.

SF_{cool} = Assumed savings factor for total household cooling energy consumption due to installation of advanced thermostat, including 0.65% additional savings for thermostat optimization services. See Table 43.

Common Inputs

Table 43. Advanced Thermostat Savings Factors

| Decision / Action Type | Heating Savings Factor ¹²⁵ | Cooling Savings Factor ¹²⁶ |
|------------------------|---------------------------------------|---------------------------------------|
| Early Replacement | 8.0% | 8.0% |
| New Construction | 5.6% | 8.0% |

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

0.00106 = MJ per BTU.

MEASURE LIFE

The expected measure life of installed equipment is estimated to be 10 years.¹²⁷

MEASURE COST

For early replacement, measure costs, including labor and equipment, for installing an advanced thermostat is \$225. For new construction, the incremental cost between a programmable and advanced thermostat is assumed to be \$150.¹²⁸

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Heating Fuel Type

For greater accuracy, the following variables could also be collected:

- Heating System Capacity
- Cooling System Capacity
- Presence of Central Cooling System

¹²⁵ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 154, footnote 15

¹²⁶ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 153, footnote 11

¹²⁷ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 207

¹²⁸ Ibid.

In addition, collecting the existing thermostat type would not affect the results but would create a dataset that could be used to inform future revisions to this measure.

ENERGY CODES AND STANDARDS

Not Applicable.

2.4.2 ADVANCED WOOD HEATING – CENTRAL PELLET SYSTEMS

CHS Measure ID: CI_HVAC_AWHC

Market Sector: Commercial/Industrial

End Use: HVAC

Applicable Building Types: Non-Residential, Multifamily Common Areas

Decarbonization Pathways: Advanced Wood Heating

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of advanced central wood pellet heating systems less than 340,000 Btu/h in existing C/I buildings, displacing a fossil fuel system and serving as the primary heating system. Eligible systems include hydronic heater or forced air furnace systems with a full load efficiency of 85% or higher based on higher heating value (HHV), and an emissions rate of less than 0.08 lbs/MMBTU of fine particulate matter (less than 2.5 microns).

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed system is a central pellet system with an assumed efficiency of 86% satisfying at least 90% of the building's heating load. The system is assumed to be installed according to manufacturer specifications and burn only pellets throughout its lifetime. It is assumed that the owner follows all manufacturer recommendations for regular cleaning to maintain the rated efficiency.

ELIGIBILITY CRITERIA

Eligible wood heating systems include all of the following characteristics:

- EPA-certified for pellet burning
- Full load efficiency \geq 85% (HHV) as certified by EPA
- PM_{2.5} emissions rate $<$ 0.08 lbs/MMBTU as certified by EPA
- Is the primary heating system for the zone(s) it serves

This characterization is intended for fossil fuel to advanced wood heating conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 44 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Certified efficiency of new pellet system: 86%
- Baseline efficiencies per Table 45
- Pellet system meets 90% of the annual heating load

Table 44. Example C/I Central Pellet System CO₂e Reductions

| Baseline Heating Fuel | Existing Capacity [Btu/h] | Lifetime CO ₂ e reductions [g], Thermal Sector | Lifetime CO ₂ e reductions [g], Total | Lifetime Credits |
|-----------------------|---------------------------|---|--|------------------|
| Natural Gas | 91,562 | 69,587,700 | 69,587,700 | 69.6 |
| Propane | | 89,827,760 | 89,827,760 | 89.8 |
| Fuel Oil #2 | | 122,268,740 | 122,268,740 | 122.3 |
| Unknown | | 48,419,905 | 48,419,905 | 48.4 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reductions [g] due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{pellet}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (\text{Cl}_{\text{oil}} + \text{Cl}'_{\text{oil}})$$

$$\text{Propane: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (\text{Cl}_{\text{LP}} + \text{Cl}'_{\text{LP}})$$

$$\text{Natural gas: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times \text{Cl}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$CO2e_{base} = ((\%Oil \times E_{hl} \times (CI_{oil} + CI'_{oil})) / \eta_{ave,oil}) + ((\%LP \times E_{hl} \times (CI_{LP} + CI'_{LP})) / \eta_{ave,LP}) + ((\%NG \times E_{hl} \times CI_{NG}) / \eta_{ave,NG}) / (1 - TDL_{NG}) + ((\%Elec \times E_{hl} \times CI_{elec}) / \eta_{ave,elec}) / (1 - TDL_{elec}) + ((\%Wood \times E_{hl} \times (CI_{wood} + CI'_{wood})) / \eta_{ave,wood})$$

Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 45)

$\eta_{ave,fuel}$ = Average heating efficiency by fuel type [dimensionless] (see Table 45)¹²⁹

Table 45. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | C/I Sector % | Average Heating Efficiency ($\eta_{ave,fuel}$) |
|------------------|--------------|--|
| Oil | 15% | 0.81 |
| Propane (LP) | 29% | 0.88 |
| Natural Gas (NG) | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$CO2e_{pellet} = \text{Annual } CO2e \text{ emissions [g] due to pellet system operation} = (E_{hl} / \eta_{pellet}) \times (CI_{pellet} + CI'_{wood})$$

η_{pellet} = Rated pellet heating system efficiency = 86%.¹³⁰

CI_{pellet} = Carbon intensity of wood pellets [g CO2e/MJ]

$$E_{hl} = \text{Heating load served by the pellet system [MJ]} = (\%Pellet \times Btuh \times EFLH) \times 0.00106$$

%Pellet = Percentage of annual heating load provided by pellet system¹³¹

| Decision/Action Type | %Pellet |
|-------------------------|---------|
| Retrofit ¹³² | 90% |

Btuh = Rated output capacity of pellet heater in Btu’s per hour [Btu/h]

¹²⁹ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).
¹³⁰ Efficiency Vermont 2023 TRM. “Weighted average efficiency of qualified models available on Renewable Energy Resource Center, “Small Scale Renewable Energy Incentive Program.”
(SSREIP) Advanced Wood Pellet Heating System Eligible Equipment Inventory,” June 6, 2016.
¹³¹ Efficiency Vermont 2023 TRM. “Energy & Research Solutions, “Emerging Technologies Research Report,” (report prepared for the Regional Evaluation, Measurement, and Verification Forum, February 13, 2013): page 9-22.”
¹³² Efficiency Vermont 2023 TRM. “Efficiency of existing wood heating systems based on professional judgment.”

EFLH = Heating equivalent full load hours = 1,062 ¹³³

0.00106 = MJ per BTU.

Non-Thermal Sector CO2e Impacts: None

Common Inputs

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is 18 years.¹³⁴

MEASURE COST

| Decision/Action Type | Cost Type | Cost |
|-------------------------|-----------|----------|
| Retrofit ¹³⁵ | Full | \$20,000 |

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- Output capacity (Btuh) in Btu's per hour [Btu/h]
- Decision/Action Type: MOP or Retrofit
- Efficient equipment full load efficiency, HHV (η_{eff})

ENERGY CODES AND STANDARDS

All new wood heating appliances offered for sale in the US are required to meet New Source Performance Standards (NSPS)¹³⁶ promulgated by the US EPA. The NSPS requires that appliances meet specified particulate matter emission limits, revised most recently in 2020. The NSPS does not prescribe minimum efficiencies but requires manufacturers to have the efficiency tested and certified by an accredited laboratory.

¹³³ Efficiency Vermont 2023 TRM. "Commercial FLH is a weighted average of commercial FLH values from New York Joint Utilities," New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs (Version 4)," April 29, 2016 and Vermont building data provided by Cadmus. See file EVT_Commercial EFLH_Analysis_July 2017.xlsx for calculation details."

¹³⁴ Midpoint of 12 – 25 year range for pellet stoves specified in EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case. <https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf>, accessed August 23, 2024.

¹³⁵ Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers & Furnaces. "Pellet boiler installed cost from Energy & Research Solutions, "Emerging Technologies Research Report," (report prepared for the Regional Evaluation, Measurement, and Verification Forum, February 13, 2013): page 9-2. Pellet furnace installed costs are assumed to be similar to pellet boiler costs."

¹³⁶ 40 CFR Part 60. <https://www.federalregister.gov/documents/2015/03/16/2015-03733/standards-of-performance-for-new-residential-wood-heaters-new-residential-hydronic-heaters-and>, accessed August 23, 2024.

The EPA maintains a certified wood heater database where certified emissions and efficiency values are listed by make and model. (<https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.about>).

2.4.3 ADVANCED WOOD HEATING – PELLET STOVES

CHS Measure ID: CI_HVAC_AWHS

Market Sector: Commercial/Industrial

End Use: HVAC

Applicable Building Types: Non-Residential, Multifamily Common Areas

Decarbonization Pathways: Advanced Wood Heating

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of advanced pellet stoves in existing C/I buildings. It is assumed that the stove supplements an existing space heating system and offsets a portion of the existing system's fuel consumption. To use this characterization, new stoves must have certified efficiencies and PM_{2.5} emissions rates of at least 70% and no more than 2.0 g/hr, respectively. (PM_{2.5} refers to "fine particles" having an aerodynamic diameter of 2.5 microns or less.)

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed system is a new pellet or wood stove at least 70% efficient supplementing an existing heating system. The system is assumed to be installed according to manufacturer specifications and burn only the fuel it is certified for throughout its lifetime. It is assumed that the owner follows all manufacturer recommendations for regular cleaning to maintain the rated efficiency.

ELIGIBILITY CRITERIA

Eligible wood heating systems must meet both of the following requirements as certified by the EPA (see <https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.about>):

- Efficiency ≥ 70%
- PM_{2.5} ≤ 2.0 g/hr

This characterization is intended for displacement of fossil fuel consumption by pellet stoves. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 46 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Certified efficiency of new stove: 77%
- Stove offsets 64% of annual heating load
- Baseline heating efficiencies per
- Existing heating system capacity = 91,562 Btu/h

Table 46. Example C/I Pellet Stove CO₂e Reductions

| Baseline Heating Fuel | Existing Capacity [Btu/h] | Lifetime CO ₂ e reductions [g], Thermal Sector | Lifetime CO ₂ e reductions [g], Total | Lifetime Credits |
|-----------------------|---------------------------|---|--|------------------|
| Natural Gas | 91,562 | 45,085,312 | 45,085,312 | 45.1 |
| Propane | | 59,478,244 | 59,478,244 | 59.5 |
| Fuel Oil #2 | | 82,547,385 | 82,547,385 | 82.5 |
| Unknown | | 30,032,658 | 30,032,658 | 30.0 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reductions [g]} \text{ due to wood stove operation} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{pellet}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g]} \text{ from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$CO2e_{base} = ((\%Oil \times E_{hl} \times (CI_{oil} + CI'_{oil})) / \eta_{ave,oil}) + ((\%LP \times E_{hl} \times (CI_{LP} + CI'_{LP})) / \eta_{ave,LP}) + ((\%NG \times E_{hl} \times CI_{NG}) / \eta_{ave,NG}) / (1 - TDL_{NG}) + ((\%Elec \times E_{hl} \times CI_{elec}) / \eta_{ave,elec}) / (1 - TDL_{elec}) + ((\%Wood \times E_{hl} \times (CI_{wood} + CI'_{wood})) / \eta_{ave,wood})$$

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 47)

$\eta_{ave,fuel}$ = Average heating efficiency by fuel type [dimensionless] (see Table 47)¹³⁷

Table 47. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | C/I Sector % | Average Heating Efficiency ($\eta_{ave,fuel}$) |
|------------------|--------------|--|
| Oil | 15% | 0.81 |
| Propane (LP) | 29% | 0.88 |
| Natural Gas (NG) | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$CO2e_{pellet} = \text{Annual } CO2e \text{ emissions [g] due to stove operation} = (E_{hl} / \eta_{eff}) \times (CI_{pellet} + CI'_{wood})$$

η_{eff} = Certified efficiency of new stove.¹³⁸

| Stove Type | Efficiency (η_{eff}) |
|------------|-----------------------------|
| Pellet | 77% |

CI_{pellet} = Carbon intensity of wood pellets [g CO2e/MJ]

$$E_{hl} = \text{Wood stove heating load in megajoules [MJ]} = (\%Stove \times \text{Capacity} \times \text{EFLH}) \times 0.00106$$

%Stove = Percentage of annual heating load provided by stove, by type:

| Stove Type | %Stove |
|-----------------------|--------|
| Pellet ¹³⁹ | 64% |

Capacity = Average capacity of primary space heating system.

¹³⁷ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

¹³⁸ Average efficiency of new stoves meeting PM2.5 ≤ 2.0 and 70% efficiency requirements on EPA list of certified wood heaters as of August 2024.

¹³⁹ 2023 Vermont Tier III TRM. “%stove for pellet stoves is calculating using: the percentage of primary (70%) versus supplemental (30%) pellet users in Vermont and the annual tons of pellets burned by primary (4.4) versus supplemental (3.3) pellet users from Vermont Department of Commercial/Industrial Installed Measures

EFLH = Heating equivalent full load hours for stove = 1,062¹⁴⁰

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts: None

Common Inputs

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is 18 years.¹⁴¹

MEASURE COST

For retrofits, the measure cost is the total installed cost of the new stove:

| Stove Type | Stove Cost | Installation Cost | Other Costs* | Total Installed Cost |
|------------|------------|-------------------|--------------|----------------------|
| Pellet | \$3,366 | \$340 | \$694 | \$4,400 |

*Costs not included in "stove cost" or "installation cost," such as miscellaneous parts or recycling fees.

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- Primary heating system capacity (Capacity) [Btu/h]
- Efficient equipment full load efficiency, HHV (η_{eff})

ENERGY CODES AND STANDARDS

All new wood heating appliances offered for sale in the US are required to meet New Source Performance Standards (NSPS)¹⁴² promulgated by the US EPA. The NSPS requires that appliances meet specified particulate

Forests, Parks, and Recreation, "Vermont Residential Fuel Assessment for the 2014-2015 Heating Season," March 2016, pages 7-8; an average annual heat load of 80.832 MMBtu for Vermont homes (700 gallons/oil per year based on 2016 VT Tier III TAG agreement/84.2% oil heating system efficiency in existing VT homes); 77% stove efficiency based on data received by Efficiency Vermont on 08/21/2017 from the upcoming NMR Vermont Residential Market Assessment; and 16.4 MMBtu/ton heat content from the November 2016 VT Fuel Price Report. %stove is calculated as ((70% (4.4 tons/yr * 16.4 MMBtu/ton * 77% / 80.832)) + (30% (3.3 tons/yr * 16.4 MMBtu/ton * 77% / 80.832))). See %stove tab in file EVT_Pellet Wood Stove_Analysis_Aug 2018_v2.xlsx for calculation."

¹⁴⁰ Efficiency Vermont 2023 TRM. "Commercial FLH is a weighted average of commercial FLH values from New York Joint Utilities, "New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs (Version 4)," April 29, 2016 and Vermont building data provided by Cadmus. See file EVT_Commercial EFLH_Analysis_July 2017.xlsx for calculation details."

¹⁴¹ Midpoint of 12 – 25 year range for pellet stoves specified in EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case. <https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf>, accessed August 23, 2024.

¹⁴² 40 CFR Part 60. <https://www.federalregister.gov/documents/2015/03/16/2015-03733/standards-of-performance-for-new-residential-wood-heaters-new-residential-hydronic-heaters-and>, accessed August 23, 2024.

matter emission limits, revised most recently in 2020. The NSPS does not prescribe minimum efficiencies but requires manufacturers to have the efficiency tested and certified by an accredited laboratory.

The EPA maintains a certified wood heater database where certified emissions and efficiency values are listed by make and model.¹⁴³

¹⁴³ <https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.about>

2.4.4 AIR SOURCE HEAT PUMP – FULL DISPLACEMENT

CHS Measure ID: CI_HVAC_HPDPF

Market Sector: Commercial/Industrial

End Use: HVAC

Applicable Building Types: Non-Residential, Multifamily Common Areas

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of a Northeast Energy Efficiency Partnerships (NEEP) certified cold climate air source heat pumps (ccASHP) in commercial or industrial buildings, displacing a fossil fuel system and serving as the primary heating system. The heat pump is assumed to operate down to an outdoor temperature of -5 °F – +5 °F.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing A/C presence and determine cooling impacts on a per site basis. If the building is confirmed to have an existing A/C system, the algorithm assumes no cooling impacts. If there is no existing A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont buildings with existing cooling systems.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is a NEEP-certified cold climate ducted or non-ducted air source heat pump serving as the primary heating source.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed system is an air source heat pump meeting NEEP efficiency standards for ducted or non-ducted central air conditioning heat pumps:
 - Ducted: SEER2 \geq 14.3, HSPF2 \geq 7.7
 - Non-Ducted: SEER2 \geq 15, HSPF2 \geq 7.5
 - COP at 5 °F \geq 1.75 at maximum capacity operation)¹⁴⁴
- Switchover temperature of 5 °F or lower
- Heat pump cooling capacity of < 65,000 Btu/h

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 48 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Heat pump meets NEEP minimum efficiency standards
- Existing A/C presence is unknown

Table 48. Example C/I ASHP-Full Displacement CO₂e Reductions

| Heat Pump Type | Baseline Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Total | Lifetime Credits per Ton _R |
|----------------|-----------------------|--|---|---------------------------------------|
| Ducted | Natural Gas | 21,684,484 | 21,478,327 | 21.7 |
| | Propane | 25,204,199 | 24,998,042 | 25.2 |
| | Fuel Oil #2 | 31,752,746 | 31,546,589 | 31.8 |
| | Unknown | 16,547,787 | 16,341,630 | 16.5 |
| Non-Ducted | Natural Gas | 21,593,313 | 21,396,777 | 21.6 |
| | Propane | 25,113,029 | 24,916,492 | 25.1 |
| | Fuel Oil #2 | 31,661,575 | 31,465,039 | 31.7 |
| | Unknown | 16,456,616 | 16,260,080 | 16.5 |

¹⁴⁴ NEEP Cold Climate Air Source Heat Pump Specification (Version 4.0). https://neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final_1.pdf, accessed August 15, 2024.

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g] due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{HPheat}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO}_2\text{e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 49)¹⁴⁵

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 49)¹⁴⁶

¹⁴⁵ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. "Other" fuel category removed.

¹⁴⁶ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

Table 49. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | C/I Sector % | Average Heating Efficiency ($\eta_{ave, fuel}$) |
|------------------|--------------|---|
| Oil | 15% | 0.81 |
| Propane (LP) | 29% | 0.88 |
| Natural Gas (NG) | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$CO2e_{HPheat} = \text{Annual } CO2e \text{ emissions [g] due to heat pump heating operation} = (E_{hl} / (HSPF2/CF) \times 3.412) \times C_{elec} / (1 - TD_{Lelec})$$

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh]. Use actual or assume 7.7 (Ducted), 7.5 (Non-Ducted) if unknown.

CF = Conversion Factor, HSPF2 to HSPF.¹⁴⁷

| Heat Pump Type | CF |
|----------------|------|
| Ducted | 0.85 |
| Non-Ducted | 0.90 |

3.412 = Btu per Watt-hour. Used to convert HSPF [Btu/(Watt hour)] to COP [dimensionless]. COP = HSPF2/3.412.

$$E_{hl} = \text{Heating load served by the heat pump [MJ]} = (HCAP_{47F} \times EFLH_{heat}) \times 0.00106$$

HCAP_{47F} = Rated heating output capacity of heat pump at 47 °F in Btu's per hour [Btu/h]

EFLH_{heat} = Equivalent full load heating hours = 1,681 hours.¹⁴⁸

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{HPcool} = \text{CO2e emissions impact [g] due to added cooling load} = (\Delta E_{cool} \times C_{elec}) / (1 - TD_{Lelec})$$

$$\Delta E_{cool} = \text{Cooling energy impacts [MJ]} = -((1 - \%Cool) \times (CCAP \times EFLH_{cool}) / SEER2) \times 0.0036$$

¹⁴⁷ Illinois TRM v12.0. "Consortium for Energy Efficiency (CEE), Testing, Testing, M1, 2, 3, Transitioning to New Federal Minimum Standards, CEE Summer Program Meeting, August, 2022."

¹⁴⁸ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source "EFLH analysis 2024-08-21" workbook.

%Cool = Presence of existing cooling. ¹⁴⁹

| Existing Cooling? | %Cool |
|-------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

CCAP = Rated cooling output capacity of heat pump in Btu's per hour [Btu/h]

SEER2 = Seasonal Energy Efficiency Rating2 (SEER2) for heat pump (cooling efficiency) [Btu/Wh] = 14.3 (Ducted), 15.0 (Non-Ducted).

EFLH_{cool} = Equivalent full load cooling hours = 591 hours. ¹⁵⁰

0.0036 = MJ per Watt-hour.

Common Inputs

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 16 years. ¹⁵¹

MEASURE COST

The assumed full retrofit cost of air source heat pumps is below:

| Capacity (Btu/h) | Ducted ¹⁵² | Non-Ducted, Single Head ¹⁵³ | Non-Ducted, Multi- Head ¹⁵⁴ |
|------------------|-----------------------|--|--|
| 6,000 | | \$2,760 | |
| 9,000 | \$1,517 | \$2,764 | |
| 12,000 | \$1,688 | \$2,761 | |
| 15,000 | \$1,803 | \$2,894 | |

¹⁴⁹ Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England

¹⁵⁰ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). "The commercial EFLH heating and cooling hours are sourced from the New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs, version 4, January 2017 (New York TRM). Hours are based on an average between the city of Massena and Albany; with it being an average between old and new building types and weighted by small commercial buildings."

¹⁵¹ Illinois TRM v12.0. "Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse 'ComEd Effective Useful Life Research Report', May 2018."

¹⁵² Vermont 2023 Act 56 Tier III TRM. "Analysis can be found on the Retrofit Cost tab of evt-centrally-ducted-ashp-analysis-Tier III 9 24 2019.xlsx. Mid-Atlantic Technical Reference Manual, version 7.0, May 2017."

¹⁵³ Vermont 2023 Act 56 Tier III TRM. "Cost analysis of Vermont installed Cold Climate Heat Pumps through Efficiency Vermont's program. Distributor reported costs analyzed in Upstream EVT CCHP Program Data_Cost Analysis.xlsx."

¹⁵⁴ Ibid.

| Capacity (Btu/h) | Ducted ¹⁵² | Non-Ducted, Single Head ¹⁵³ | Non-Ducted, Multi- Head ¹⁵⁴ |
|------------------|-----------------------|--|--|
| 18,000 | \$2,111 | \$3,132 | \$3,495 |
| 24,000 | \$3,240 | \$3,426 | \$3,992 |
| 30,000 | \$3,601 | | \$3,754 |
| 36,000 | \$4,461 | | \$4,343 |
| 40,000 | | \$3,981 | |
| 42,000 | \$5,079 | | \$5,036 |
| 48,000 | \$5,498 | | \$5,481 |
| 54,000 | \$6,019 | | |
| 56,500 | | \$4,631 | |
| 60,000 | \$7,532 | | |
| 66,000 | \$6,275 | | |
| 72,000 | \$6,491 | | |

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity at 47 °F of heat pump (HCAP_{47F}).
- Rated cooling capacity of heat pump (CCAP).

For greater accuracy, the following variables could also be collected:

- Backup heating fuel
- Existing A/C presence

ENERGY CODES AND STANDARDS

NEEP Cold Climate Air Source Heat Pump Specification, Version 4.0.

2.4.5 AIR SOURCE HEAT PUMP – PARTIAL DISPLACEMENT

CHS Measure ID: CI_HVAC_HPDP

Market Sector: Commercial/Industrial

End Use: HVAC

Applicable Building Types: Non-Residential, Multifamily Common Areas

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of air source heat pumps in C/I buildings that partially displace fossil fuel-based heating. The heat pump is assumed to serve as the primary heating system above approximately 35 °F; below this temperature, heating is provided by a fossil fuel system, either integrated with the heat pump or controlled separately.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing A/C presence and determine cooling impacts on a per site basis. If the building is confirmed to have an existing A/C system, the algorithm assumes no cooling impacts. If there is no existing A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont buildings with existing cooling systems.

Baseline Conditions

The assumed baseline may be one of the following conditions:

3. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
4. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is an ENERGY STAR-certified split system or single package heat pump providing heating above an outdoor temperature of approximately 35 °F. The heat pump is assumed to be oversized relative to the load at the switchover temperature.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed system is an air source heat pump meeting ENERGY STAR efficiency standards for ducted or non-ducted central air conditioning heat pumps:

- Split Systems: SEER2 ≥ 15.2, EER2 ≥ 11.7, HSPF2 ≥ 7.8
- Single Package: SEER2 ≥ 15.2, EER2 ≥ 10.6, HSPF2 ≥ 7.2¹⁵⁵
- Heat pump is installed to supplement a fossil fuel system.
- Heat pump cooling capacity of < 65,000 Btu/h

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 50 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Heat pump meets ENERGY STAR minimum efficiency standards
- Existing A/C presence is unknown

Table 50. Example C/I ASHP-Partial Displacement CO₂e Reductions

| Heat Pump Type | Baseline Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Total | Lifetime Credits per Ton _R |
|----------------|-----------------------|--|---|---------------------------------------|
| Split System | Natural Gas | 6,735,778 | 6,541,828 | 6.7 |
| | Propane | 7,826,890 | 7,632,939 | 7.8 |
| | Fuel Oil #2 | 9,856,939 | 9,662,989 | 9.9 |
| | Unknown | 5,143,402 | 4,949,452 | 5.1 |
| Single Package | Natural Gas | 6,648,589 | 6,454,638 | 6.6 |
| | Propane | 7,739,701 | 7,545,750 | 7.7 |
| | Fuel Oil #2 | 9,769,750 | 9,575,800 | 9.8 |
| | Unknown | 5,056,213 | 4,862,262 | 5.1 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_{2e\text{thermal}} = \text{Annual thermal sector CO}_{2e} \text{ reductions in grams [g]} = \Delta\text{CO}_{2e\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_{2e\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_{2e}$$

¹⁵⁵ NEEP Cold Climate Air Source Heat Pump Specification (Version 4.0). https://neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final_1.pdf, accessed August 15, 2024.

1,000,000 = Grams per metric ton

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g] due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{HPheat}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO}_2\text{e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 51)¹⁵⁶

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 51)¹⁵⁷

Table 51. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | C/I Sector % | Average Heating Efficiency (η_{ave}) |
|------------------|--------------|--|
| Oil | 15% | 0.81 |
| Propane (LP) | 29% | 0.88 |
| Natural Gas (NG) | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$\text{CO}_2\text{e}_{\text{HPheat}} = \text{Annual CO}_2\text{e emissions [g] due to heat pump heating operation} = (E_{\text{hl}} / (\text{HSPF}_2 / \text{CF}) \times 3.412) \times CI_{\text{elec}} / (1 - \text{TDL}_{\text{elec}})$$

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh]. Use actual or assume 7.8 (Split System), 7.2 (Single Package) if unknown.

3.412 = Btu per Watt-hour. Used to convert HSPF [Btu/(Watt hour)] to COP [dimensionless]. COP = HSPF2/3.412.

¹⁵⁶ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. "Other" fuel category removed.

¹⁵⁷ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

CF = Conversion Factor, HSPF2 to HSPF.¹⁵⁸

| Heat Pump Type | CF |
|----------------|------|
| Ducted | 0.85 |
| Non-Ducted | 0.90 |

$$E_{hl} = \text{Heating load served by the heat pump [MJ]} = (\text{HF} \times \text{HCAP}_{47F} \times \text{EFLH}_{\text{heat}}) \times 0.00106$$

HF = Heatload Factor, reduces EFLH to account for partial displacement.= 31%.¹⁵⁹

HCAP_{47F} = Rated heating output capacity of heat pump at 47 °F in Btu’s per hour [Btu/h]

EFLH_{heat} = Equivalent full load heating hours = 1,681 hours.¹⁶⁰

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta\text{CO2e}_{\text{HPcool}} = \text{CO2e emissions impact [g]} \text{ due to added cooling load} = (\Delta E_{\text{cool}} \times \text{Cl}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cool}} = \text{Cooling energy impacts [MJ]} = -((1 - \% \text{Cool}) \times (\text{CCAP} \times \text{EFLH}_{\text{cool}}) / \text{SEER2}) \times 0.0036$$

%Cool = Presence of central cooling.¹⁶¹

| Central Cooling? | %Cool |
|------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

CCAP = Rated cooling output capacity of heat pump in Btu’s per hour [Btu/h]

SEER2 = Seasonal Energy Efficiency Rating2 (SEER2) for heat pump (cooling efficiency) [Btu/Wh] = 15.2 (Split System or Single Package)

EFLH_{cool} = Equivalent full load cooling hours = 591 hours.¹⁶²

0.0036 = MJ per Watt-hour.

Common Inputs

¹⁵⁸ Illinois TRM v12.0. “Consortium for Energy Efficiency (CEE), Testing, Testing, M1, 2, 3, Transitioning to New Federal Minimum Standards, CEE Summer Program Meeting, August, 2022.”

¹⁵⁹ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Based on the ratio of EFLH for a partial displacement heat pump providing 35 °F and above to EFLH for a full displacement heat pump. Source: “EFLH analysis 2024-08-21” workbook.

¹⁶⁰ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source “EFLH analysis 2024-08-21” workbook.

¹⁶¹ Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England

¹⁶² Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). “The commercial EFLH heating and cooling hours are sourced from the New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs, version 4, January 2017 (New York TRM). Hours are based on an average between the city of Massena and Albany; with it being an average between old and new building types and weighted by small commercial buildings.”

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 16 years.¹⁶³

MEASURE COST

The assumed full retrofit cost of air source heat pumps is below:

| Capacity (Btu/h) | Ducted ¹⁶⁴ | Non-Ducted, Single Head ¹⁶⁵ | Non-Ducted, Multi-Head ¹⁶⁶ |
|------------------|-----------------------|--|---------------------------------------|
| 6,000 | | \$2,760 | |
| 9,000 | \$1,517 | \$2,764 | |
| 12,000 | \$1,688 | \$2,761 | |
| 15,000 | \$1,803 | \$2,894 | |
| 18,000 | \$2,111 | \$3,132 | \$3,495 |
| 24,000 | \$3,240 | \$3,426 | \$3,992 |
| 30,000 | \$3,601 | | \$3,754 |
| 36,000 | \$4,461 | | \$4,343 |
| 40,000 | | \$3,981 | |
| 42,000 | \$5,079 | | \$5,036 |
| 48,000 | \$5,498 | | \$5,481 |
| 54,000 | \$6,019 | | |
| 56,500 | | \$4,631 | |
| 60,000 | \$7,532 | | |
| 66,000 | \$6,275 | | |
| 72,000 | \$6,491 | | |

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity at 47 °F of heat pump (HCAP_{47F}).
- Rated cooling capacity of heat pump (CCAP).

For greater accuracy, the following variables could also be collected:

¹⁶³ Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.”

¹⁶⁴ Vermont 2023 Act 56 Tier III TRM. “Analysis can be found on the Retrofit Cost tab of evt-centrally-ducted-ashp-analysis-Tier III 9 24 2019.xlsx. Mid-Atlantic Technical Reference Manual, version 7.0, May 2017.”

¹⁶⁵ Vermont 2023 Act 56 Tier III TRM. “Cost analysis of Vermont installed Cold Climate Heat Pumps through Efficiency Vermont’s program. Distributor reported costs analyzed in Upstream EVT CCHP Program Data_Cost Analysis.xlsx.”

¹⁶⁶ Ibid.

- Backup heating fuel
- Existing A/C presence

ENERGY CODES AND STANDARDS

ENERGY STAR Product Specification for Central Air Conditioner and Heat Pump Equipment, Version 6.1.

2.4.6 AIR-TO-WATER HEAT PUMPS

CHS Measure ID: CI_HVAC_AWHP

Market Sector: Commercial/Industrial

End Use: HVAC

Applicable Building Types: Non-Residential, Multifamily Common Areas

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of an air-to-water heat pump in commercial/industrial hydronic heating systems, displacing a fossil fuel boiler and serving as the primary heating source. The heat pump is assumed to operate down to an outdoor temperature of 5°F to +5°F, at which point the auxiliary heating system assumes the full heating load.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing A/C presence and determine cooling impacts on a per site basis. If the building is confirmed to have an existing A/C system, the algorithm assumes no cooling impacts. If there is no existing A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont buildings with existing cooling systems.

This characterization does not include the use of air-to-water heat pumps for domestic hot water heating.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is an air-to-water heat pump serving as the primary heating source above -5°F to +5°F.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed system is an air to water heat pump (AWHP)
- Heat pump capacity of ≤ 72,000 Btu/h

- AWHP must be capable of generating 110°F supply water at an outdoor temperature of 5°F with a COP of 1.7 or greater.
- Switchover temperature of 5°F or lower

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 52 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for C/I AWHPs over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- AWHP COP_{heat} = 2.83
- Existing A/C system presence is unknown

Table 52. Example C/I AWHP CO₂e Reductions

| Existing Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Total | Lifetime Credits per Ton _R |
|-----------------------|--|---|---------------------------------------|
| Natural Gas | 22,379,172 | 22,097,185 | 22.4 |
| Propane | 25,898,887 | 25,616,901 | 25.9 |
| Fuel Oil #2 | 32,447,434 | 32,165,447 | 32.4 |
| Unknown | 17,242,475 | 16,960,488 | 17.2 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g]} \text{ due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{HPheat}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g]} \text{ from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 53)¹⁶⁷

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 53)¹⁶⁸

Table 53. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | Fuel % | Average Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|--------------|--------|---|
| Oil | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural Gas | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$\text{CO2e}_{\text{HPheat}} = \text{Annual CO2e emissions [g]} \text{ due to heat pump heating operation} = (E_{\text{hl}} / \text{COP}_{\text{hp}}) \times CI_{\text{elec}} / (1 - \text{TDL}_{\text{elec}})$$

COP_{hp} = Coefficient of Performance (COP) rating for heat pump (heating efficiency) [dimensionless]. Use average COP over operating conditions or refer to Table 54 if unknown.

$$E_{\text{hl}} = \text{Heating load served by the heat pump [MJ]} = (\text{HCAP}_{47\text{F}} \times \text{EFLH}_{\text{heat}}) \times 0.00106$$

$\text{HCAP}_{47\text{F}}$ = Rated heating output capacity of heat pump at 47 °F in Btu’s per hour [Btu/h]

$\text{EFLH}_{\text{heat}}$ = Equivalent full load heating hours = 1,681 hours.¹⁶⁹

Non-Thermal Sector CO2e Impacts:

$$\Delta \text{CO2e}_{\text{HPcool}} = \Delta \text{CO2e emissions due to added cooling load} = (\Delta E_{\text{cool}} \times CI_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

¹⁶⁷ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed.

¹⁶⁸ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

¹⁶⁹ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 55 °F or 60 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source “EFLH analysis 2024-08-21” workbook.

$$\Delta E_{cool} = \text{Cooling energy impacts [MJ]} = -((1 - \%Cool) \times (CCAP \times EFLH_{cool}) / COP_{hp}) \times 0.00106$$

$\%Cool$ = Percent of Vermont facilities with existing cooling.¹⁷⁰

| Existing Cooling? | $\%Cool$ |
|-------------------|----------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

CCAP = Rated cooling output capacity of heat pump in Btu’s per hour [Btu/h]

EFLH_{cool} = Equivalent full load cooling hours = 591 hours.¹⁷¹

Common Inputs

Table 54. Default AWHP Efficiency

| Rated Heating Capacity [tons _R] | COP _{hp} ¹⁷² |
|---|----------------------------------|
| 2.0 | 2.75 |
| 2.5 | 2.76 |
| 3.0 | 2.78 |
| 3.5 | 2.90 |
| 4.0 | 3.03 |
| 4.5 | 2.87 |
| 5.0 | 2.71 |
| 5.5 | 2.80 |
| 6.0 | 2.89 |
| Overall Average | 2.83 |

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI’ = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

0.00106 = MJ per Btu.

¹⁷⁰ Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England.

¹⁷¹ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). “Residential EFLH Cooling is calculated in an analysis of heat pump metered data. The partial load of each heat pump is summed up through the heating season, and taken as an average across all units metered. This analysis can be found on the EFLH Calculator tab in the EVT_CCHP MOP and Retrofit_2018_.xlsx.”

¹⁷² Vermont 2023 Act 56 Tier III TRM. “The values in the [...] table are a result of weighted averages of available equipment from local distributors binned across Burlington, VT weather data down to an outdoor air temperature of 0°F, averaged across 100°F, 110°F, and 120°F supply water temperatures.”

MEASURE LIFE

The expected measure life is assumed to be comparable to an air-to-air heat pump: 16 years.¹⁷³

MEASURE COST

The assumed measure costs of air-to-water heat pumps are below. These figures include the cost of the AWHP plus additional low temperature emitters, estimated to be \$1,336.¹⁷⁴ Low temperature emitters are typically needed with an AWHP installation to allow the AWHP to meet the design load of the building. Existing emitters, often cast iron or older baseboard emitters, were designed for the high supply water temperatures delivered by fossil fuel boilers and do not function well with the lower supply water temperatures produced by AWHPs.

| Rated heating capacity [tons] | Retrofit Cost ¹⁷⁵ |
|-------------------------------|------------------------------|
| 2 | \$6,404 |
| 3 | \$8,248 |
| 4 | \$10,199 |

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity of heat pump (HCAP).
- Rated cooling capacity of heat pump (CCAP).

For greater accuracy, the following variables could also be collected:

- Backup heating fuel
- Existing A/C presence

ENERGY CODES AND STANDARDS

N/A

¹⁷³ Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.”

¹⁷⁴ Vermont 2023 Act 56 Tier III TRM. ““Optimizing Hydronic System Performance in Residential Applications”, NREL, October 2013 (page 8). The cost of low temperature hydronic emitters represents a straight average of the three efficiency scenarios incremental costs’ that were modeled in the report.”

¹⁷⁵ Vermont 2023 Act 56 Tier III TRM. “The installation cost is sourced from estimates of two local manufacturers who compared the installation of air to water heat pumps to that of; (1) multi-head mini-split heat pumps, and (2) low temperature condensing boilers. As a result, the estimated installation cost for these two measures was sourced from NEEP Incremental Cost Studies (\$893 for a boiler and \$1,736 for a multi-head mini-split heat pump) and averaged accordingly.”

2.4.7 GROUND SOURCE HEAT PUMP

CHS Measure ID: CI_HVAC_GSHP

Market Sector: Commercial/Industrial

End Use: HVAC

Applicable Building Types: Non-Residential

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of ENERGY STAR-qualified ground source heat pumps in C/I buildings, displacing fossil fuel systems. Ground source heat pumps (GSHP), also known as geothermal heat pumps, utilize the ground or groundwater as a thermal energy source to efficiently provide space conditioning. This characterization supports six types of GSHP systems as defined in ENERGY STAR specifications for geothermal heat pump systems:

- Water-to-Air, Closed Loop
- Water-to-Air, Open Loop
- Water-to-Water, Closed Loop
- Water-to-Water, Open Loop
- DGX-to-Air
- DGX-to-Water

“Closed Loop” refers to systems in which the heat transfer fluid (typically a water-based solution) is permanently contained in a closed piping system.

“Open Loop” refers to systems that use pumped groundwater from an aquifer or well as a heat source.

“DGX” stands for “Direct Geoexchange” and refers to systems in which the refrigerant is used as the heat transfer fluid instead of a secondary heat transfer fluid such as water.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing central A/C presence and determine cooling impacts on a per site basis. If the building is confirmed to have an existing central A/C system, the algorithm assumes no cooling impacts. If there is no existing central A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing central A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont buildings with existing central cooling systems.

GSHP systems can provide domestic water heating through add-on systems called desuperheaters. This characterization does not include desuperheaters.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is an ENERGY STAR-qualified GSHP serving as the primary heating system.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed GSHP is ENERGY STAR-qualified and meets ENERGY STAR minimum heating (COP) and cooling (EER) efficiencies:¹⁷⁶

Table 55. ENERGY STAR GSHP Minimum Heating and Cooling Efficiency

| GSHP Type | EER (Cooling) | COP (Heating) |
|----------------------------|------------------|------------------|
| Water-to-Air | | |
| Closed Loop Water-to-Air | 17.1 | 3.6 |
| Open Loop Water-to-Air | 21.1 | 4.1 |
| Water-to-Water | | |
| Closed Loop Water-to-Water | 16.1 | 3.1 |
| Open Loop Water-to-Water | 20.1 | 3.5 |
| DGX | | |
| DGX-to-Air | 16.0 | 3.6 |
| DGX-to-Water | 15.0 | 3.1 |

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

¹⁷⁶ ENERGY STAR® Program Requirements Product Specification for Geothermal Heat Pumps: Eligibility Criteria Version 3.2. <https://www.energystar.gov/sites/default/files/asset/document/Geothermal%20Heat%20Pumps%20Version%203.2%20Final%20Specification.pdf>, accessed September 2, 2024.

DECARBONIZATION SUMMARY

Table 56 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- GSHP meets ENERGY STAR minimum efficiency standards
- Existing A/C presence is unknown

Table 56. Example C/I GSHP Lifetime CO₂e Reductions per Ton_R

| GSHP Type | Baseline Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Total | Lifetime Credits per Ton _R |
|-----------------------------|-----------------------|--|---|---------------------------------------|
| Water-to-Air, Closed Loop | Natural Gas | 36,397,925 | 36,171,184 | 36.4 |
| | Propane | 41,864,359 | 41,637,618 | 41.9 |
| | Fuel Oil #2 | 52,073,979 | 51,847,238 | 52.1 |
| | Unknown | 28,184,133 | 27,957,393 | 28.2 |
| Water-to-Air, Open Loop | Natural Gas | 36,741,675 | 36,557,918 | 36.7 |
| | Propane | 42,208,109 | 42,024,352 | 42.2 |
| | Fuel Oil #2 | 52,417,729 | 52,233,972 | 52.4 |
| | Unknown | 28,527,884 | 28,344,127 | 28.5 |
| Water-to-Water, Closed Loop | Natural Gas | 35,943,287 | 35,702,463 | 35.9 |
| | Propane | 41,409,721 | 41,168,897 | 41.4 |
| | Fuel Oil #2 | 51,619,341 | 51,378,517 | 51.6 |
| | Unknown | 27,729,496 | 27,488,672 | 27.7 |
| Water-to-Water, Open Loop | Natural Gas | 36,317,389 | 36,124,490 | 36.3 |
| | Propane | 41,783,823 | 41,590,924 | 41.8 |
| | Fuel Oil #2 | 51,993,443 | 51,800,544 | 52.0 |
| | Unknown | 28,103,598 | 27,910,699 | 28.1 |
| DGX-to-Air | Natural Gas | 36,397,925 | 36,155,595 | 36.4 |
| | Propane | 41,864,359 | 41,622,029 | 41.9 |
| | Fuel Oil #2 | 52,073,979 | 51,831,649 | 52.1 |
| | Unknown | 28,184,133 | 27,941,804 | 28.2 |
| DGX-to-Water | Natural Gas | 35,943,287 | 35,684,802 | 35.9 |
| | Propane | 41,409,721 | 41,151,236 | 41.4 |
| | Fuel Oil #2 | 51,619,341 | 51,360,857 | 51.6 |
| | Unknown | 27,729,496 | 27,471,011 | 27.7 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HPheat}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 57)¹⁷⁷

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 57)¹⁷⁸

Table 57. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | Fuel % | Average Heating Efficiency (η_{heat}) |
|--------------|--------|---|
| Oil | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural Gas | 22% | 0.88 |

¹⁷⁷ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. "Other" fuel category removed.

¹⁷⁸ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

| Heating Fuel | Fuel % | Average Heating Efficiency (η_{heat}) |
|--------------|--------|---|
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

$$\text{CO2e}_{\text{HPheat}} = \text{Annual CO2e emissions [g] due to heat pump heating operation} = (E_{\text{hl}} / \text{COP}) \times \text{Cl}_{\text{elec}} / (1 - \text{TDL}_{\text{elec}})$$

COP = Rated heating Coefficient of Performance (COP) for heat pump [dimensionless] under ISO 13256-1 test conditions. Use actual or assume ENERGY STAR minimum standard (see Table 55).

$$E_{\text{hl}} = \text{Heating load served by the heat pump [MJ]} = (\text{HCAP} \times \text{EFLH}_{\text{heat}}) \times 0.00106$$

$\text{HCAP}_{47\text{F}}$ = Rated heating output capacity of heat pump in Btu's per hour [Btu/h]

$\text{EFLH}_{\text{heat}}$ = Equivalent full load heating hours = 1,681 hours.¹⁷⁹

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta\text{CO2e}_{\text{HPcool}} = \text{CO2e emissions impact [g] due to added cooling load} = (\Delta E_{\text{cool}} \times \text{Cl}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cool}} = \text{Cooling energy impacts [MJ]} = -((1 - \% \text{Cool}) \times (\text{CCAP} \times \text{EFLH}_{\text{cool}}) / \text{EER}) \times 0.0036$$

$\% \text{Cool}$ = Presence of existing cooling.¹⁸⁰

| Central Cooling? | $\% \text{Cool}$ |
|------------------------|------------------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 68% |

CCAP = Rated cooling output capacity of heat pump in Btu's per hour [Btu/h]

EER = Energy Efficiency Rating (EER) for heat pump (cooling efficiency) under ISO 13256-1 test conditions [Btu/Wh]. Use actual or assume ENERGY STAR minimum standard (see Table 55).

$\text{EFLH}_{\text{cool}}$ = Equivalent full load cooling hours = 591 hours.¹⁸¹

¹⁷⁹ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 55 °F or 60 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source "EFLH analysis 2024-08-21" workbook.

¹⁸⁰ Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England.

¹⁸¹ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). "The commercial EFLH heating and cooling hours are sourced from the New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs, version 4, January 2017 (New York TRM). Hours are based on an average between the city of Massena and Albany; with it being an average between old and new building types and weighted by small commercial buildings."

0.0036 = MJ per Watt-hour.

Common Inputs

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The largest cost component of GSHP installations is typically the wellfields or ground loops. If installed properly, the underground piping should not need replacement. While the heat pump itself may need replacement within a more normal lifespan for energy efficiency measures, the cost of the heat pump is usually significantly less than the wellfields or ground loops. Accordingly, this measure is granted a measure life of 25 years, reflecting the long lifespan of the ground piping.¹⁸²

MEASURE COST

The cost of GSHP installations varies widely with the specific conditions of each site. Accordingly, the actual installed cost (material, labor, and miscellaneous costs) of each GSHP installation should be tracked.

- For retrofits, \$3957 per ton may be assumed for planning purposes.¹⁸³

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity of heat pump (HCAP).
- Rated cooling capacity of heat pump (CCAP).
- Type of GSHP installed:
 - Closed Loop Water-to-Air
 - Open Loop Water-to-Air
 - Closed Loop Water-to-Water
 - Open Loop Water-to-Water
 - DGX-to-Air
 - DXG-to-Water
- Existing heating fuel

For greater accuracy, the following variables could also be collected:

¹⁸² Consistent with New York TRM v11 and Illinois TRM v12.0 measure life assumptions.

¹⁸³ Illinois TRM v12.0. "Based on data provided in 'Results of Home geothermal and air source heat pump rebate incentives documented by IL electric cooperatives'."

- Rated COP of heat pump (COP)
- Rated EER of heat pump (EER)
- Existing central A/C presence

ENERGY CODES AND STANDARDS

ENERGY STAR® Program Requirements Product Specification for Geothermal Heat Pumps: Eligibility Criteria
Version 3.2.

2.4.8 VARIABLE REFRIGERANT FLOW (VRF) HEAT PUMP SYSTEMS

CHS Measure ID: CI_HVAC_VRFL

Market Sector: Commercial/Industrial

End Use: HVAC

Applicable Building Types: Non-Residential

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Electricity, Wood

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of cold climate air source variable refrigerant flow (VRF) systems in commercial or industrial buildings, displacing fossil fuel heating. VRF systems, also known as variable refrigerant volume (VRV) systems, are multi-zone heat pump systems in which the flow of refrigerant to zone terminal units is modulated according to heating or cooling demand. VRFs are often paired with a separate ventilation system called a dedicated outdoor air system (DOAS). This characterization does not include any effects that may be associated with changes to ventilation systems as part of a VRF installation.

Cold climate VRF systems are commercially available that can efficiently provide heating to an outdoor air temperature of -5°F , with the newest technology claiming -22°F .¹⁸⁴ A fossil fuel backup heating source may be needed in Vermont. This characterization assumes that the VRF serves as the primary heating system down to a switchover temperature of -5°F to $+5^{\circ}\text{F}$.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing A/C presence and determine cooling impacts on a per site basis. If the building is confirmed to have an existing A/C system, the algorithm assumes no cooling impacts. If there is no existing A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont buildings with existing cooling systems.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

¹⁸⁴ Slipstream, "MN Department of Commerce TRMAC: Cold Climate VRF – Does It Work in Minnesota?" November 29, 2023.

Proposed Conditions

The proposed condition is a NEEP-certified VRF multi-split heat pump system providing heating above an outdoor temperature of -5 °F to +5 °F and serving as the primary heating source.

ELIGIBILITY CRITERIA

The installed system is VRF multi-split heat pump system meeting NEEP efficiency standards:¹⁸⁵

Table 58. NEEP VRF Multi-Split Heat Pump Efficiency Requirements

| Capacity [Btu/h] | Heating | | | Cooling |
|-----------------------|--------------|--------------|-------------|---------|
| | COP @ 47 ° F | COP @ 17 ° F | COP @ 5 ° F | IEER |
| ≥65,000 and <135,000 | 3.40 | 2.25 | 1.55 | 18.9 |
| ≥135,000 and <240,000 | 3.25 | 2.07 | 1.50 | 18.0 |
| ≥240,000 | 3.20 | 2.05 | 1.45 | 17.0 |

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 59 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for VRF systems over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- VRF meets NEEP minimum efficiency standards (see Table 58)
- Existing A/C presence is unknown
- VRF capacity is ≥65,000 and <135,000

Table 59. Example VRF Lifetime CO₂e Reductions

| Existing Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Total | Lifetime Credits per Ton _R |
|-----------------------|--|---|---------------------------------------|
| Natural Gas | 22,834,097 | 22,678,115 | 22.8 |
| Propane | 26,353,812 | 26,197,831 | 26.4 |
| Fuel Oil #2 | 32,902,359 | 32,746,377 | 32.9 |
| Unknown | 17,697,400 | 17,541,418 | 17.7 |

¹⁸⁵ NEEP Cold Climate Air Source Heat Pump Specification (Version 4.0). https://neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final_1.pdf, accessed September 15, 2024.

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HPheat}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 60)¹⁸⁶

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 60)¹⁸⁷

Table 60. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | %Fuel | Average Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|--------------|-------|---|
| Oil | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural Gas | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

¹⁸⁶ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. "Other" fuel category removed.

¹⁸⁷ Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figures 49 and 50. Assumed 75% heating efficiency for wood (source: Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces) and 80% efficiency for unitary equipment propane and natural gas heating (source: professional judgement).

$$CO2e_{HPheat} = \text{Annual CO2e emissions [g] due to heat pump heating operation} = (E_{hl} / COP_{47F}) \times Cl_{elec} / (1 - TDL_{elec})$$

COP_{47F} = Heating coefficient of performance (heating efficiency) for VRF at 47 °F [dimensionless]. Use actual if known or assume minimum requirement based on capacity, as shown in Table 58

$$E_{hl} = \text{Heating load served by the heat pump [MJ]} = (HCAP_{47F} \times EFLH_{heat}) \times 0.00106$$

$HCAP_{47F}$ = Rated heating output capacity of heat pump at 47 °F in Btu’s per hour [Btu/h]

$EFLH_{heat}$ = Equivalent full load heating hours = 1,681 hours.¹⁸⁸

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{HPcool} = \text{CO2e emissions impact [g] due to added cooling load} = (\Delta E_{cool} \times Cl_{elec}) / (1 - TDL_{elec})$$

$$\Delta E_{cool} = \text{Cooling energy impacts [MJ]} = -((1 - \%Cool) \times (CCAP \times EFLH_{cool}) / IEER) \times 0.0036$$

$\%Cool$ = Presence of existing cooling.¹⁸⁹

| Existing Cooling? | %Cool |
|-------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown | 68% |

$CCAP$ = Rated cooling output capacity of heat pump in Btu’s per hour [Btu/h]

$IEER$ = Integrated Energy Efficiency Ratio for VRF (cooling efficiency) [Btu/Wh]. Use actual if known or assume minimum requirement based on capacity, as shown in Table 58.

$EFLH_{cool}$ = Equivalent full load cooling hours = 591 hours.¹⁹⁰

0.0036 = MJ per Watt-hour.

Common Inputs

Cl = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

Cl' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

¹⁸⁸ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source “EFLH analysis 2024-08-21” workbook.

¹⁸⁹ Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England

¹⁹⁰ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). “The commercial EFLH heating and cooling hours are sourced from the New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs, version 4, January 2017 (New York TRM). Hours are based on an average between the city of Massena and Albany; with it being an average between old and new building types and weighted by small commercial buildings.”

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 16 years.¹⁹¹

MEASURE COST

The installed cost of a VRF system retrofit is highly variable and site-specific. Accordingly, actual costs should be used if available. An assumed measure cost is not available at this time.

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity at 47 °F of VRF (HCAP_{47F}).
- Rated cooling capacity of VRF heat pump (CCAP).
- Baseline heating fuel

For greater accuracy, the following variables could also be collected:

- Rated COP at 47 °F of VRF (COP_{47F})
- Rated IEER of VRF (IEER)
- Existing A/C presence

ENERGY CODES AND STANDARDS

To use this characterization, VRF systems must conform with the NEEP Cold Climate Air Source Heat Pump Specification (Version 4.0).

Federal standards set minimum COP and IEER requirements for VRF systems in 10 CFR 431(g)(2).

¹⁹¹ Illinois TRM v12.0. "Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse 'ComEd Effective Useful Life Research Report', May 2018."

2.5 MISCELLANEOUS

2.5.1 HEAT PUMP POOL WATER HEATER

CHS Measure ID: CI_MISC_HPPW

Market Sector: Commercial/Industrial

End Use: Miscellaneous

Applicable Building Types: Non-Residential, Multifamily Common Areas

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the replacement of an existing fossil fuel pool water heater with a heat pump pool water heater providing heat to in-ground, outdoor pools. The heat pump pool water heater uses heat pump technology to transfer heat from the air to pool water. Pool heating is used to heat the pool at the beginning of the season and counteract heat losses due to evaporation and convection.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical conventional pool heater consuming a representative mix of oil, natural gas, propane, and electricity. This scenario is suitable if the baseline heater fuel is not collected.
2. The existing oil, natural gas or propane pool heater. This scenario is suitable if the baseline heater fuel is collected.

Proposed Conditions

The proposed condition is a heat pump pool water heater.

ELIGIBILITY CRITERIA

This measure is only applicable to non-residential and multifamily common area in-ground outdoor pools and does not apply to spas. The pool heater must have a COP of at least 4.0.

This characterization is intended for fuel switching scenarios. Electric heaters are only considered as a baseline component when the baseline heater fuel is not collected.

DECARBONIZATION SUMMARY

Table 61 provides estimated lifecycle decarbonization ranges for example baseline and proposed conditions over the effective useful life of the measure. The lifetime CO₂e reductions are applied on a per square foot

basis. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Average baseline pool heater efficiencies in Table 62
- Heat pump pool water heater COP = 4.79
- Pool kept at 82 °F from June 1 through September 30
- Pool cover use unknown
- Pool surface area is 4,000 ft² and volume is 150,000 gallons

Table 61. Example C/I Heat Pump Pool Water Heater CO₂e Reductions

| Baseline Fuel | Lifetime CO ₂ e reductions per SF [g], Thermal Sector | Lifetime CO ₂ e reductions per SF [g], Total | Lifetime Credits |
|---------------|--|---|------------------|
| Oil | 318,367,190 | 318,367,190 | 318.4 |
| Propane | 278,144,684 | 278,144,684 | 278.1 |
| Natural Gas | 239,931,981 | 239,931,981 | 239.9 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g]} \text{ due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{HP}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g]} \text{ from baseline pool water heater}$$

$$\text{Oil: } \text{CO}_2\text{e}_{\text{base}} = E_{\text{load}} / \eta_{\text{ave,oil}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \text{CO}_2\text{e}_{\text{base}} = E_{\text{load}} / \eta_{\text{ave,LP}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: } \text{CO}_2\text{e}_{\text{base}} = (E_{\text{load}} / \eta_{\text{ave,NG}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$\eta_{ave,fuel}$ = Assumed average pool water heater efficiency by fuel (see Table 62)¹⁹²

Table 62. Vermont Pool Water Heating Efficiency, C/I Buildings

| Pool Water Heating Fuel | Average Efficiency ($\eta_{ave,fuel}$) |
|-------------------------|--|
| Oil | 0.85 |
| Propane (LP) | 0.85 |
| Natural Gas | 0.85 |

$$CO2e_{HP} = CO2e \text{ emissions from heat pump pool water heater [g]} = (E_{load} / COP_{HP} \times Cl_{elec}) / (1 - TD_{L_{elec}})$$

COP_{HP} = Coefficient of performance (COP) of proposed heat pump pool water heater [dimensionless]. Use actual or assume 4.79 if unknown.¹⁹³

Non-Thermal Sector CO2e Impacts: None

Common Inputs

E_{load} = Annual pool water heating load [MJ] =

$$= (((BTU_{perSF_{surface}} + BTU_{perSF_{evap}} - BTU_{perSF_{solar}}) \times A_{water}) + (BTU_{perGal_{reheat}} \times V_{water})) \times 0.00106$$

A_{water} = Surface area of water in square feet [ft²], from application.

V_{water} = Pool water capacity in gallons [gal], from application

$BTU_{perSF_{surface}}$ = Annual heating energy load contributed by convection/radiation heat losses via pool surface, per square foot. Based on the hourly temperature for Springfield, Montpelier, Rutland, and Burlington, applied to a pool kept at 82 °F from June 1 to September 30.

$$= 263,045 \text{ Btu/ft}^2 \text{ (no pool cover)}$$

$$= 217,871 \text{ Btu/ft}^2 \text{ (pool covered from 8pm to 8am)}$$

$$= 240,458 \text{ Btu/ft}^2 \text{ (pool cover use unknown)}^{194}$$

$BTU_{perGal_{reheat}}$ = Annual heating energy load contributed by heating the full volume of pool water, per gallon. Based on heating one gallon from a temperature of 52 °F¹⁹⁵ to 82 °F.

¹⁹² Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater, fossil fuel heater efficiency. “85% to be conservative - Allen Pools says 85 to 90%; Poultney pools said 82-84%. Find analysis information on Pool Calcs tab of document: Heat Pump Pool Water Heater Calcs_2021_Final version.xlsx”

¹⁹³ Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. “The minimum required efficiency is COP 4.0 for all sizes of heat pump pool heaters. While we reviewed decreasing to minimum standards, the VT pool market shows a greater COP value. Poultney Pools offers Hayward Summit XL #SUMXL140 with a COP 5.7 at peak performance. Allen Pools offers Hayward Summit XL as well, for in ground pools. We found a weighted average of COP, based on the average air temperature during these months.”

¹⁹⁴ A simple average is assumed in the absence of data on prevalence of pool cover use.

¹⁹⁵ Average ground water temperature for Burlington, Montpelier, Rutland, and Springfield, VT from U.S. DOE Standard Building America DHW Schedules, May 2014

$$= 250 \text{ Btu/gal}$$

$BTU_{\text{perSF}_{\text{evap}}}$ = Annual heating energy load contributed by evaporation, per square foot. Based on the hourly temperature and relative humidity values for Springfield, Montpelier, Rutland, and Burlington, applied to a pool kept at 82 °F from June 1 to September 30.

$$= 3,312 \text{ Btu/ft}^2 \text{ (no pool cover)}$$

$$= 3,294 \text{ Btu/ft}^2 \text{ (pool covered from 8pm to 8am)}$$

$$= 3,303 \text{ Btu/ft}^2 \text{ (pool cover use unknown)}$$

$BTU_{\text{perSF}_{\text{solar}}}$ = Annual solar heat gain, per square foot. Based on Global Horizontal Incidence modified to account for cloud cover and a solar absorptance factor of 0.77.¹⁹⁶

$$= 88,086 \text{ Btu/ft}^2 \text{ (with or without pool cover)}$$

COP_{HP} = Coefficient of performance (COP) of proposed heat pump pool water heater [dimensionless]. Use actual or assume 4.79 if unknown.¹⁹⁷

$$0.00106 = \text{MJ per BTU}$$

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 5 years.¹⁹⁸

MEASURE COST

The retrofit cost of a heat pump pool water heater is \$4,200.¹⁹⁹

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- Fuel type and efficiency of existing pool heater (η_{base})
- COP of proposed heat pump water heater (COP_{hp})

¹⁹⁶ Buscemi, A. et al. *A Novel Model to Assess the Energy Demand of Outdoor Swimming Pools*. Energy Conversion and Management, 2024.

¹⁹⁷ Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. "The minimum required efficiency is COP 4.0 for all sizes of heat pump pool heaters. While we reviewed decreasing to minimum standards, the VT pool market shows a greater COP value. Poultney Pools offers Hayward Summit XL #SUMXL140 with a COP 5.7 at peak performance. Allen Pools offers Hayward Summit XL as well, for in ground pools. We found a weighted average of COP, based on the average air temperature during these months."

¹⁹⁸ Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. "5 years is based on the parts warranty on heat pump pool water heaters."

¹⁹⁹ Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. "This is the actual cost of a Hayward Heat Pump Pool Water Heater. Find further information on Assumptions tab of document: Heat Pump Pool Water Heater Calcs_2021_Final version.xlsx"

- Use of pool cover and estimated hours of use
- Surface area of pool water in square feet (A_{water})
- Full volume of pool water in gallons (V_{water})

ENERGY CODES AND STANDARDS

Minimum efficiencies for pool heaters are prescribed in federal standard 10 CFR 430.32(k)(2).

3. RESIDENTIAL INSTALLED MEASURES

3.1 APPLIANCES

3.1.1 HEAT PUMP CLOTHES DRYERS

CHS Measure ID: RE_APPL_HPCD

Market Sector: Residential

End Use: Appliances

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Electricity

Decision/Action Type: MOP

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This characterization involves installing a residential heat pump clothes dryer to replace a conventional gas dryer. Heat pump clothes dryers use efficient heat pump technology for heating the dryer air instead of conventional gas or electric heating elements. Hybrid heat pump dryers may also use this characterization. These products use a heat pump as the primary heating source, but also include a secondary gas or electric heating element that may be enabled to dry the clothes faster.

This characterization includes indirect space heating and cooling impacts resulting from the measure. Clean heat credits are awarded based on direct impacts and indirect space heating impacts.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical conventional dryer consuming a representative mix of natural gas, propane, and electricity. This scenario is suitable for Downstream offerings in which the baseline dryer fuel is not collected.
2. A minimum efficiency natural gas or propane dryer. This scenario is suitable for Downstream offerings in which the baseline dryer fuel is collected.

Proposed Conditions

The proposed condition is a heat pump or hybrid heat pump clothes dryer.

ELIGIBILITY CRITERIA

The efficient dryer must be an ENERGY STAR-certified full heat pump or hybrid heat pump model. Both standard and compact-sized units are eligible in this characterization.

This characterization is intended for fuel switching scenarios. Electric dryers are only considered as a baseline component when the baseline dryer fuel is not collected.

DECARBONIZATION SUMMARY

Table 63 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- ENERGY STAR-certified standard-sized (≥ 4.4 ft³) dryer, heat pump or hybrid heat pump
- Central A/C presence is unknown/not collected
- Space heating fuel type is unknown/not collected
- Building type (single family or multifamily) is unknown/not collected

Table 63. Example Residential Heat Pump Clothes Dryer CO₂e Reductions

| ENERGY STAR Most Efficient? | Baseline Dryer Fuel | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------------------|---------------------|---|--|------------------|
| No | Natural Gas | 2,794,260 | 2,792,665 | 2.79 |
| | Propane | 3,170,773 | 3,169,178 | 3.17 |
| | Unknown | 1,466,730 | 1,465,127 | 1.47 |
| Yes | Natural Gas | 2,708,301 | 2,707,490 | 2.71 |
| | Propane | 3,084,814 | 3,084,003 | 3.08 |
| | Unknown | 1,380,771 | 1,379,952 | 1.38 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}} + \Delta\text{CO}_2\text{e}_{\text{heat}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g] due to equipment replacement} = \text{CO}_2\text{e}_{\text{base dryer}} - \text{CO}_2\text{e}_{\text{hp dryer}}$$

$$\text{CO}_2\text{e}_{\text{base dryer}} = \text{Annual CO}_2\text{e emissions [g] from baseline dryer}$$

If baseline dryer fuel is known:

$$\text{Propane: CO2e}_{\text{base dryer}} = E_{\text{base dryer}} \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base dryer}} = (E_{\text{base dryer}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$E_{\text{base dryer}} = \text{Baseline dryer energy usage} = \text{Load} / \text{CEF}_{\text{base}} \times 3.6$$

$$\text{CEF}_{\text{base}} = \text{Minimum Combined Energy Factor (CEF) for vented gas dryer [lbs/kWh]} \\ = 2.84.^{200}$$

If baseline dryer fuel is unknown:

$$\text{CO2e}_{\text{base dryer}} = (((\% \text{Elec}_{\text{df}} \times \text{Load} \times CI_{\text{elec}}) / \text{CEF}_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}})) + ((\% \text{NG}_{\text{df}} \times \text{Load} \times CI_{\text{NG}}) / \text{CEF}_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + (\% \text{LP}_{\text{df}} \times \text{Load} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \text{CEF}_{\text{ave,LP}} \times 3.6$$

$$E_{\text{base dryer}} = ((\% \text{Elec}_{\text{df}} \times \text{Load}) / \text{CEF}_{\text{ave,elec}} + (\% \text{NG}_{\text{df}} \times \text{Load}) / \text{CEF}_{\text{ave,NG}} + (\% \text{LP}_{\text{df}} \times \text{Load}) / \text{CEF}_{\text{ave,LP}}) \times 3.6$$

$\% \text{Elec}_{\text{df}}$, etc. = Relative proportion of fuel in Vermont's dryer fuel mix. See Table 64.²⁰¹

CEF_{ave} = Average Combined Energy Factor (CEF) of baseline dryers by fuel. See Table 64.²⁰²

Table 64. Clothes Dryer Fuel Mix and Average Efficiency, Residential Buildings

| Dryer Fuel | Building Type | | | Assumed Dryer Efficiency (CEF _{ave,fuel}) |
|------------------|---------------|-------------|---------|---|
| | Single Family | Multifamily | Unknown | |
| Electricity | 81% | 77% | 81% | 3.11 |
| Natural Gas (NG) | 15% | 21% | 16% | 2.84 |
| Propane (LP) | 4% | 3% | 4% | 2.84 |

$$\text{CO2e}_{\text{hp dryer}} = \text{Annual CO2e emissions [g]} \text{ from heat pump or hybrid dryer} = (E_{\text{hp dryer}} \times CI_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$E_{\text{hp dryer}} = \text{Load} / \text{CEF}_{\text{hp}} \times 3.6$$

$$\text{CEF}_{\text{hp}} = \text{CEF of the heat pump dryer unit based on type and ENERGY STAR level.}^{203}$$

²⁰⁰ Illinois Technical Reference Manual. V12.0. Based on federal standards and adjusted to CEF-D2 (equivalent to as if tested under Appendix D2 as performed in the ENERGY STAR analysis. Units are lbs/kWh for gas and electric dryers.

²⁰¹ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Electricity Fuel Type includes electricity (208V/240V) and electricity (110V). The single family and multifamily results are combined for the "unknown" building type category by weighting according to the population of each building type in the respective studies.

²⁰² Illinois Technical Reference Manual. V12.0. September 2023. ENERGY STAR Draft 2 Version 1.0 Clothes Dryers Data and Analysis. Assumes vented electric and gas dryers.

²⁰³ Based on ENERGY STAR certified products list downloaded on 8/5/2024, <https://www.energystar.gov/productfinder/product/certified-clothes-dryers/results>. See "HP clothes dryers analysis 2024-08-05.xlsx".

Table 65. Heat Pump Clothes Dryer CEF by Type (CEF_{hp})

| Technology | Size | CEF _{hp} [lbs/kWh] | |
|--------------------------|---------------------|-----------------------------|----------------------------|
| | | ENERGY STAR | ENERGY STAR Most Efficient |
| Heat Pump | Standard | 4.30 | 9.13 |
| Heat Pump | Compact | 3.36 | 6.25 |
| Hybrid Heat Pump | Standard or Compact | 4.50 | 6.03 |
| Unknown (full or hybrid) | Standard | 4.47 | 8.17 |
| Unknown (full or hybrid) | Compact | 3.36 | 6.25 |

Annual clothes drying load

$$\text{Load} = \text{Annual clothes drying load [lbs]} = \text{Weight} \times N_{\text{cycles}}$$

$$\text{Weight} = \text{Average clothes dryer load weight [lbs]}.^{204}$$

Table 66. Average Load Weight by Dryer Size

| Dryer Size | Average Weight [lbs] |
|-----------------------------------|----------------------|
| Standard (≥ 4.4 ft ³) | 8.45 |
| Compact (< 4.4 ft ³) | 3.00 |

$$N_{\text{cycles}} = \text{Number of dryer cycles per year} = 322.^{205}$$

Space Heating Impacts

If the primary space heating fuel is known:

$$\text{Oil: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \eta_{\text{ave,oil}}$$

$$\text{Propane: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \eta_{\text{ave,LP}}$$

$$\text{Natural Gas: } \Delta\text{CO}_2\text{e}_{\text{heat}} = ((\Delta E_{\text{hl}} \times \text{CI}_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Wood: } \text{CO}_2\text{e}_{\text{wood}} = (\Delta E_{\text{hl}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})) / \eta_{\text{ave,wood}}$$

If the primary space heating fuel is unknown:

$$\Delta\text{CO}_2\text{e}_{\text{heat}} = ((\% \text{Oil} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

²⁰⁴ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 178, footnote 12

²⁰⁵ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 178, footnote 11

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 67)²⁰⁶

$\eta_{ave, fuel}$ = Average heating efficiency for each fuel type [dimensionless] (see Table 67)²⁰⁷

Table 67. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Heating Efficiency ($\eta_{ave, fuel}$) |
|------------------|---------------|-------------|---------|---|
| | Single Family | Multifamily | Unknown | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |
| Wood | 8% | 1% | 7% | 0.53 |

Change in heating load:

$$\Delta E_{hl} = -(WHHF \times \%Conditioned) \times ((HR_{base} \times E_{base \text{ dryer}}) - (HR_{hp} \times E_{hp \text{ dryer}}))$$

WHHF = Portion of reduced waste heat that results in increased heating = 0.558.²⁰⁸

%Conditioned = Portion of homes with dryer in conditioned space = 73%.²⁰⁹

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{cool} = \text{Space cooling impacts [g]} = (\Delta E_{cl} \times Cl_{elec}) / \eta_{cool} / (1 - TDLelec)$$

η_{cool} = Cooling system efficiency = 3.72.²¹⁰

Change in Cooling load:

$$\Delta E_{cl} = (WHCF \times \%Conditioned \times \%Cool) \times ((HR_{base} \times E_{dryer, base}) - (HR_{hp} \times E_{dryer, hp}))$$

WHCF = Portion of waste heat that results in increased cooling= 0.188²¹¹

²⁰⁶ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the “unknown” building type category by weighting according to the population of each building type in the respective studies.

²⁰⁷ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

²⁰⁸ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. “Based on bin analysis of annual heating hours for Burlington, VT using TMY3 data: 4885 / 8760 = 55.8%, see “Heating Penalty” tab in “2023 Clothes Dryer Analysis.xlsx”

²⁰⁹ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 176, footnote 2

²¹⁰ Calculated from statewide mean SEER = 12.7 of central air conditioner in VT from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 88: Central Air Conditioner Efficiency (SEER). COP = SEER / 3.412.

²¹¹ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. “Based on bin analysis of annual cooling hours for Burlington, VT using TMY3 data: 1650/8760 = 18.8%, see “2023 Clothes Dryer Analysis.xlsx”

%Cool = Presence of central cooling²¹²

Table 68. Percentage of Residential Customers with Central Cooling

| Central Cooling? | %Cool |
|--------------------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 7% |
| Unknown, Multifamily | 6% |
| Unknown, Building Type Unknown | 6.9% |

Common Inputs

%HR = Proportion of dryer heat energy remaining in space. Baseline dryer may be vented or ventless depending on model; assume vented if unknown. Heat pump clothes dryers are ventless.

Table 69. Portion of Dryer Heat Energy Remaining in Space

| Dryer Type | %HR ²¹³ |
|------------|--------------------|
| Vented | 5% |
| Ventless | 100% |

3.6 = MJ per kWh

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is estimated to be 12 years.²¹⁴

MEASURE COST

The market opportunity incremental cost is \$61 for ENERGY STAR units and \$412 for ENERGY STAR Most Efficient Units.²¹⁵

²¹² Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Because the sample size of multifamily new construction buildings was very small, single family new construction values were used as a proxy. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

²¹³ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. Source reference not provided.

²¹⁴ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. "Based on average lifetime in DOE Buildings Data Book <http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=5.7.15>"

²¹⁵ Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. "See "2023 Clothes Dryer Analysis_v2.xlsx", "Incremental Cost" tab. Based on DOE Life-Cycle Cost and Payback Period analysis Table

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Existing dryer fuel
- Heat pump dryer size (standard or compact)
- ENERGY STAR Most Efficient certification status

For greater accuracy, the following variables could also be collected:

- Efficient dryer technology (heat pump or hybrid heat pump)
- Primary space heating fuel
- Presence of central cooling
- Existing dryer venting (vented or ventless)

ENERGY CODES AND STANDARDS

Minimum efficiencies for residential clothes dryers are prescribed in 10 CFR § 430.32.

Installed dryers must be ENERGY STAR-certified to qualify for this characterization. As of August 2024, Version 1.1 of the ENERGY STAR Program Requirements Product Specification for Clothes Dryers is in effect.

8.3.1, <http://www.regulations.gov/contentStreamer?objectId=0900006480c8ee12&disposition=attachment&contentType=pdf>

3.1.2 INDUCTION COOKTOP

CHS Measure ID: RE_APPL_INCT

Market Sector: Residential

End Use: Appliances

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural gas, propane, electricity

Decision/Action Type: Retrofit, MOP

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of an induction cooktop in a residential home to replace a standard electric, natural gas, or propane cooktop. CO₂e savings are achieved through switching from fossil fuel usage to electricity for cooking, and through the high efficiency of an induction cooktop compared to conventional gas or electric cooktops.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical conventional cooktop consuming a representative mix of natural gas, propane, and electricity. This scenario is suitable for Downstream offerings in which the baseline cooktop fuel is not collected.
2. A minimum efficiency natural gas or propane cooktop. This scenario is suitable for Downstream offerings in which the baseline cooktop fuel is collected.

Proposed Conditions

The proposed condition is an induction cooktop.

ELIGIBILITY CRITERIA

The installed cooktop is electric induction.

DECARBONIZATION SUMMARY

Table 70 provides example lifecycle CO₂e reductions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein

Assumptions:

- Building type (single family or multifamily) is unknown/not collected

Table 70. Example Induction Cooktop CO2e Reductions

| Existing Cooktop Fuel | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
|-----------------------|--|-------------------------------------|------------------|
| Natural Gas | 1,841,689 | 1,841,689 | 1.8 |
| Propane | 2,145,661 | 2,145,661 | 2.1 |
| Unknown | 1,112,029 | 1,112,029 | 1.1 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{induction}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] of baseline cooktop:}$$

If baseline fuel is known:

$$\text{Propane: } \text{CO2e}_{\text{base}} = E_{\text{base,LP}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: } \text{CO2e}_{\text{base}} = E_{\text{base,NG}} \times \text{CI}_{\text{NG}} / (1 - \text{TDL}_{\text{NG}})$$

If baseline fuel is unknown:

$$\text{CO2e}_{\text{base}} = (\% \text{LP}_{\text{cook}} \times E_{\text{base,LP}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) + (\% \text{NG}_{\text{cook}} \times E_{\text{base,NG}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}}) + (\% \text{Elec}_{\text{cook}} \times E_{\text{base,elec}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

%LP, etc. = Relative proportion of cooktop fuel in Vermont residential buildings²¹⁶

Table 71. Cooktop Fuel Mix in Vermont Residential Buildings

| Cooktop Fuel | Building Type | | |
|--------------|---------------------|-------------------|---------------|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel |
| Electric | 46% | 55% | 47% |
| Propane (LP) | 42% | 3% | 38% |

²¹⁶ NMR 2023, 2020 Vermont Single Family Existing Homes Baseline Study, Table 150 and NMR 2023, 2020 Vermont Multifamily Residential Baseline Study, Table 139. Mix for unknown building type calculated as weighted-average of single family and multifamily using relative population sizes in each study, approximately 90% single family and 10% multifamily.

| Cooktop Fuel | Building Type | | |
|------------------|---------------------|-------------------|---------------|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel |
| Natural Gas (NG) | 12% | 42% | 15% |

$$CO2e_{induction} = \text{Annual } CO2e \text{ emissions of electric induction cooktop [g]} = (E_{induction} \times CI_{elec}) / (1 - TDL_{elec})$$

Non-Thermal Sector CO2e Impacts: None

Common Inputs:

E_{base} = Energy consumption of baseline cooktop in megajoules [MJ]
 = (Heat Up Energy + Simmer Energy + Saute Energy) x Days. See Table 72. Standard electric derived from induction cooktop values assuming cooking efficiencies of 0.74 and 0.84, respectively. ²¹⁷

$E_{induction}$ = Energy consumption of electric induction cooktop [MJ]
 = (Heat Up Energy + Simmer Energy + Saute Energy) x Days. See Table 72.

Table 72. Cooktop Energy Usage

| Cooktop Fuel ²¹⁸ | Heat Up Energy [MJ/Day] | Simmer Energy [MJ/Day] | Saute Energy [MJ/Day] | Total Energy [MJ/Day] ($E_{base}, E_{induction}$) |
|-----------------------------|-------------------------|------------------------|-----------------------|---|
| Electricity (Standard) | 2.32 | 0.98 | 0.76 | 4.06 |
| Electricity (Induction) | 2.05 | 0.86 | 0.67 | 3.58 |
| Natural Gas | 5.43 | 1.77 | 1.40 | 8.60 |
| Propane | 5.43 | 1.77 | 1.40 | 8.60 |

Days = Cooking days per year = 260.²¹⁹

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The measure life for an induction cooktop is 15 years.²²⁰

²¹⁷ Energy+Environmental Economics. *Residential Building Electrification in California: Consumer economics, greenhouse gases and grid impacts*. April 2019. Figure 2-8, p. 34.

²¹⁸ Standard electric, natural gas, and propane energy figures from 2023 Vermont Tier III TRM, Residential Induction Stovetop. "Analysis can be found on Residential Induction Stovetops tab on Residential Induction Cooking Tier III Analysis 9_25_2019.xlsx."

²¹⁹ 2023 Vermont Tier III TRM, Residential Induction Stovetop. "Table 6: Energy Model Assumptions, Residential Cooktop Performance Energy Comparison, Frontier Energy, July 2019."

²²⁰ 2023 Vermont Tier III TRM, Residential Induction Stovetop. "Energy Conservation Program: Energy Conservation Standards for Residential Conventional Oven, 2015, Department of Energy, Page 103, residential_ovens_nopr.pdf."

MEASURE COST

Retrofit: The actual installed cost of the induction cooktop should be used if possible; if unknown, assume \$2,100.²²¹

MOP:

- Assume an incremental cost of \$300 for replacing standard electric cooktops, and \$200 for replacing natural gas or propane cooktops.²²²
- Assume an incremental cost of \$247 if the existing cooktop fuel is unknown.²²³

PROGRAM DATA TRACKING RECOMMENDATIONS

Downstream program designs should track the existing cooktop fuel.

ENERGY CODES AND STANDARDS

10 CFR 430.32(j)(1) prescribes maximum integrated annual energy consumption (IAEC) for electric and gas cooktops.

²²¹ Energy+Environmental Economics. *Residential Building Electrification in California: Consumer economics, greenhouse gases and grid impacts*. April 2019. Figure 2-8, p. 34. Induction stovetops: midpoint of \$1,900-\$2,300 range; gas stovetops: midpoint of \$1,400-\$2,200 range; standard electric stovetops: midpoint of \$1,700-\$2,100 range.

²²² Ibid.

²²³ Weighted-average of electric, natural gas, and propane incremental costs using unknown building type mix in Table 2.

3.2 BUILDING ENVELOPE

3.2.1 AIR SEALING

CHS Measure ID: RE_ENVE_AIRS

Market Sector: Residential

End Use: Envelope

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Weatherization

Applicable Baseline Fuels: Natural gas, propane, fuel oil #2, electricity, wood, kerosene

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves sealing the envelope of a home to prevent air leakage. Air sealing measures include applying spray foam, weatherstripping, and caulking to seal gaps in the thermal envelope that allow air to leak in or out. Air leakage leads to heat loss, which causes the heating system to have to run more to maintain the temperature setpoint. Air leakage also has negative non-energy impacts in the form of comfort issues and can lead to physical damage to the home as a result of ice dams, which are caused in part by air leakage around unsealed attic protrusions such as chimneys, plumbing stacks, and electrical wiring.

This characterization quantifies the thermal energy savings and associated emission reductions based on pre- and post-blower door readings. A blower door is an industry-standard tool for measuring the total air leakage in a home. This is a Retrofit measure in which the baseline is the existing air leakage of the home, and the proposed condition is the leakage after air sealing measures are installed. This characterization is not applicable to gut rehab/major renovation projects, which may be subject to code requirements that set a more stringent baseline condition.

Homes where extensive air sealing is installed may require installation of a mechanical ventilation system such as an Energy Recovery Ventilator (ERV) or Heat Recovery Ventilator (HRV) to maintain acceptable indoor air quality. Projects combining air sealing with mechanical ventilation installation are best analyzed as Custom measures.

In addition to heating-related emissions reductions which are eligible for clean heat credits, this characterization provides algorithms for cooling and fan/pump-energy related emissions reductions which are not eligible for credits.

Baseline Conditions

The baseline is the total air leakage volume prior to installing air sealing measures, measured with a blower door test.

Proposed Conditions

The proposed condition is the total air leakage volume after installing air sealing measures, measured with a blower door test.

ELIGIBILITY CRITERIA

Pre- and post-blower door tests are required to apply this characterization.

DECARBONIZATION SUMMARY

Table 73 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Central A/C presence is unknown/not collected
- Heating efficiencies per Table 74 (known systems/fuels) or per Table 75 (unknown systems/fuels)
- Building type (single family or multifamily) is unknown/not collected

Table 73. Example Residential Air Sealing CO₂e Reductions

| CFM50 Reduction | | System Type | Fuel | Lifetime CO ₂ e Reductions, Thermal [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------|---------------|-------------|-------------|--|--|------------------|
| Range | Assumed Value | | | | | |
| > 0 and < 800 | 400 | Boiler | Oil | 3,271,809 | 3,294,152 | 3.3 |
| | | | Propane | 2,732,376 | 2,753,534 | 2.7 |
| | | | Natural Gas | 2,508,783 | 2,530,878 | 2.5 |
| | | | Kerosene | 3,279,747 | 3,302,091 | 3.3 |
| | | Furnace | Oil | 3,391,509 | 3,414,633 | 3.4 |
| | | | Propane | 2,732,376 | 2,753,534 | 2.7 |
| | | | Natural Gas | 2,295,269 | 2,315,571 | 2.3 |
| | | | Kerosene | 3,399,738 | 3,422,862 | 3.4 |
| | | Heat Pump | Electric | 209,562 | 216,103 | 0.2 |
| | | Baseboard | Electric | 687,362 | 706,506 | 0.7 |
| Pellet Stove | Wood | 1,297,542 | 1,324,456 | 1.3 | | |
| Unknown | Unknown | 2,704,802 | 2,726,889 | 2.7 | | |
| 800 to < 1600 | 1200 | Boiler | Oil | 9,815,426 | 9,882,457 | 9.8 |
| | | | Propane | 8,197,127 | 8,260,603 | 8.2 |
| | | | Natural Gas | 7,526,348 | 7,592,635 | 7.5 |
| | | | Kerosene | 9,839,242 | 9,906,272 | 9.8 |
| | | Furnace | Oil | 10,174,527 | 10,243,899 | 10.2 |
| | | | Propane | 8,197,127 | 8,260,603 | 8.2 |
| | | | Natural Gas | 6,885,808 | 6,946,712 | 6.9 |
| | | | Kerosene | 10,199,214 | 10,268,586 | 10.2 |
| | | Heat Pump | Electric | 628,685 | 648,310 | 0.6 |
| | | Baseboard | Electric | 2,062,086 | 2,119,518 | 2.1 |
| Pellet Stove | Wood | 3,892,626 | 3,973,369 | 3.9 | | |
| Unknown | Unknown | 8,114,406 | 8,180,668 | 8.1 | | |
| > 1600 | 2000 | Boiler | Oil | 16,359,043 | 16,470,762 | 16.4 |
| | | | Propane | 13,661,878 | 13,767,671 | 13.7 |

| CFM50 Reduction | | System Type | Fuel | Lifetime CO2e Reductions, Thermal [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
|-----------------|---------------|--------------|-------------|---------------------------------------|-------------------------------------|------------------|
| Range | Assumed Value | | | | | |
| | | | Natural Gas | 12,543,914 | 12,654,392 | 12.5 |
| | | | Kerosene | 16,398,736 | 16,510,454 | 16.4 |
| | | Furnace | Oil | 16,957,545 | 17,073,165 | 17.0 |
| | | | Propane | 13,661,878 | 13,767,671 | 13.7 |
| | | | Natural Gas | 11,476,347 | 11,577,854 | 11.5 |
| | | | Kerosene | 16,998,690 | 17,114,309 | 17.0 |
| | | | Heat Pump | Electric | 1,047,808 | 1,080,517 |
| | | Baseboard | Electric | 3,436,809 | 3,532,530 | 3.4 |
| | | Pellet Stove | Wood | 6,487,710 | 6,622,281 | 6.5 |
| | | Unknown | Unknown | 13,524,010 | 13,634,447 | 13.5 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$\Delta\text{CO2e}_{\text{thermal}}$ = Total annual carbon dioxide equivalent emissions reductions in grams [g] = $\Delta\text{CO2e}_{\text{heat}}$

Annual Clean Heat Credits = $\Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$

CreditValue = 1 credit/tonneCO2e

1,000,000 = Grams per metric ton

$\Delta\text{CO2e}_{\text{heat}}$ = CO2e emissions reductions [g] from reducing heating energy

If primary heating fuel is known:

Oil: $\Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{heat}} \times (\text{Cl}_{\text{oil}} + \text{Cl}'_{\text{oil}})$

Propane: $\Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{heat}} \times (\text{Cl}_{\text{LP}} + \text{Cl}'_{\text{LP}})$

Natural Gas: $\Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{heat}} \times \text{Cl}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$

Kerosene: $\Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{heat}} \times (\text{Cl}_{\text{kerosene}} + \text{Cl}'_{\text{kerosene}})$

Wood: $\Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{hl}} / \eta_{\text{heat}} \times (\text{Cl}_{\text{wood}} + \text{Cl}'_{\text{wood}})$

Electricity: $\Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{heat}} \times \text{Cl}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$

η_{heat} = Heating system efficiency, dependent on fuel and system type²²⁴:

²²⁴ Efficiencies for fossil fuel systems and heat pumps are sourced from NMR Group, *2020 Vermont Single Family Existing Homes Baseline Study*, with the exception of propane furnaces and kerosene furnaces and boilers. Propane furnaces and the "Other" category are sourced from the *2023 Efficiency Vermont TRM*. Kerosene furnaces and boilers are assumed to have the same efficiency as oil furnaces and boilers, respectively.

Table 74. Residential Deemed Heating System Efficiencies

| System Type | Fuel | Heating Efficiency (η_{heat}) |
|-------------|-------------------------|---|
| Boiler | Oil | 0.85 |
| | Propane | 0.90 |
| | Natural gas | 0.86 |
| | Kerosene | 0.85 |
| Furnace | Oil | 0.82 |
| | Propane | 0.90 |
| | Natural gas | 0.94 |
| | Kerosene | 0.82 |
| Heat Pump | Electric | 3.28 |
| Baseboard | Electric | 1.00 |
| Other | Pellet stove | 0.70 |
| | Newer EPA woodstove | 0.60 |
| | Catalytic woodstove | 0.50 |
| | Non-catalytic woodstove | 0.40 |
| | Outdoor wood boiler | 0.25 |
| | Open hearth fireplace | 0.10 |
| | Propane stove | 0.65 |

If primary heating fuel is unknown:

$$\Delta\text{CO}_2e_{\text{heat}} = (\% \text{Oil} \times \Delta E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}}) / \eta_{\text{ave,oil}}) + (\% \text{LP} \times \Delta E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}}) / \eta_{\text{ave,LP}}) + (\% \text{NG} \times \Delta E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}} / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times \Delta E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + (\% \text{Wood} \times \Delta E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}}$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 75)²²⁵

$\eta_{\text{ave,fuel}}$ = Average heating efficiency for each fuel type [dimensionless] (see Table 75)²²⁶

Table 75. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|--------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |

²²⁵ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the "unknown" building type category by weighting according to the population of each building type in the respective studies.

²²⁶ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{ave, fuel}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |
| Wood | 8% | 1% | 7% | 0.53 |

$$\Delta E_{hl} = \text{Reduction in heating load [MJ]} = [(1.08 \times (CFM50_{pre} - CFM50_{post}) / N \times Adj_{heat} \times HDH)] \times 0.00106$$

Adj_{heat} = Heating adjustment factor to reconcile this simplified algorithm with evaluation bill analysis results = 0.55 [dimensionless].²²⁷

HDH = Heating degree hours [$^{\circ}F$ hr] = 113,443.²²⁸

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{cool} = \text{CO2e reductions [g]} \text{ from decreased cooling energy} = (\Delta E_{cl} / \eta_{cool} \times Cl_{elec}) / (1 - TD_{elec})$$

$$\Delta E_{cl} = \text{Reduction in cooling load [MJ]} = [\%Cool \times (1.08 \times (CFM50_{pre} - CFM50_{post}) / N \times Adj_{cool} \times CDH)] \times 0.00106$$

$\%Cool$ = Presence of central cooling.²²⁹

| Central Cooling? | %Cool |
|--------------------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 7% |
| Unknown, Multifamily | 6% |
| Unknown, Building Type Unknown | 6.9% |

²²⁷ Efficiency Vermont TRM Program Year 2023, HPwES 2.0 Airsealing. "This adjustment factor mirrors that which is applied to HERO-based HPwES projects. Based on the 2018 program impact evaluation and subsequent outcomes of EM&V/DPS negotiations, the 0.55 adjustment factor is intended to better align the savings estimated by HERO algorithms to those established by evaluation. Since the algorithms used by this characterization closely align with HERO, the same adjustment factor is adopted."

²²⁸ Efficiency Vermont TRM 2023, HPwES 2.0 Airsealing, calculated as average of flat, open attic (127,691 $^{\circ}F$ -hr) and basement/crawlspace rim joists and walls (99,195 $^{\circ}F$ -hr). "Heating Degree Hours for attic assumes a base temperature of 58 degrees F and uses Climate Normals data for Burlington International Airport. A recent Nest study by EVT revealed that a base temperature of 58 degrees is appropriate to capture the heating tendencies of a typical Vermont home. See referenced document "NEST VEIC Data Share 9Jun2017". In an attempt to make a conservative estimate of heating degree hours, it was assumed that only days within a defined heating season would be included in the total, assuming that homeowners would disable or set back heating systems in the off season. The heating season was defined as the time period where temperatures "consistently" fall below 58 degrees. Based on visual inspection of TMY3 data, this period was established as September 19th to May 6th. Heating Degree Hours for basement assumes a blend of conditioned and unconditioned space as reported by the Vermont Single-Family Existing Homes On-Site Report, December 21, 2017. Unconditioned space HDH assumes a base temperature of 48 degrees F based on the premise that unconditioned basements are allowed to swing in temperature, are ground coupled, and are usually cool. See worksheets "Foundation Blend" and "HDH - Climate Normals" in the 'HPwES 2.0 Support Workbook FINAL_2022' for a complete derivation."

²²⁹ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

Adj_{cool} = Cooling adjustment factor to account for people not always operating their air-conditioning systems when the outside temperature is greater than 75 °F = 0.75 [dimensionless].²³⁰

CDH = Cooling degree hours [°F hr] = 6,619.²³¹

η_{cool} = Cooling system efficiency = 3.72.²³²

$\Delta CO2e_{fan}$ = CO2e reductions [g] from decreased furnace fan or boiler pump energy = $(\Delta E_{fan} \times Cl_{elec}) / (1 - TDLelec)$

ΔE_{fan} = Reduction in furnace fan or boiler pump energy [MJ]

If heating fuel is known:

$$\Delta E_{fan} = \%Fossil \times \Delta E_{hl} / \eta_{heat} \times F_e$$

If heating fuel is unknown:

$$\Delta E_{fan} = \%Fossil \times ((\%Oil \times \Delta E_{hl} / \eta_{ave,oil}) + (\%LP \times \Delta E_{hl} / \eta_{ave,LP}) + (\%NG \times \Delta E_{hl} / \eta_{ave,NG}) + (\%Elec \times \Delta E_{hl} / \eta_{ave,elec}) + (\%Wood \times \Delta E_{hl} / \eta_{ave,wood})) \times F_e$$

$\%Fossil$ = Presence of fossil-fuel furnace or boiler.

| Fossil Fuel System? | $\%Fossil$ |
|--------------------------------|------------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 85% |
| Unknown, Multifamily | 76% |
| Unknown, Building Type Unknown | 84% |

F_e = Furnace/boiler fan/pump energy as a percentage of annual fuel consumption = 3.14%.²³³

Common Inputs:

$CFM50_{pre}$ = Pre-installation blower door reading in cubic feet per minute, measured at 50 Pascals pressure differential.

$CFM50_{post}$ = Post-installation blower door reading in cubic feet per minute, measured at 50 Pascals pressure differential.

²³⁰ Energy Center of Wisconsin, *Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research*, 2008, page 31.

²³¹ *Efficiency Vermont TRM Program Year 2023*, ERV/HRV. "Based on analysis of TMY data with 70 °F base temperature. See the 'Weather data' sheet of ERV_HRV_Analysis_2022.xlsx for more details."

²³² Calculated from statewide mean SEER = 12.7 of central air conditioner in VT from NMR Group, *2020 Vermont Single Family Existing Homes Baseline Study*, Table 88: Central Air Conditioner Efficiency (SEER). COP = SEER / 3.412.

²³³ Illinois TRM v12.0. " F_e is not one of the AHRI certified ratings provided for residential furnaces, but can be reasonably estimated from a calculation based on the certified values for fuel energy (E_f in MMBTU/yr) and E_{ae} (kWh/yr). An average of a 300 record sample (non-random) out of 1495 was 3.14%."

N = Conversion factor from volumetric airflow at 50 Pascals differential pressure to airflow at natural conditions = 17.1 [dimensionless].²³⁴

1.08 = Specific heat of air x density of air x 60 min/hr [BTU/(CFM °F hr)]

0.00106 = MJ per BTU.

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

Lifetime for air sealing is 20 years.²³⁵

MEASURE COST

Measure cost of \$3,000 per job is assumed for air sealing.²³⁶

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Heating fuel type
- Heating system type
- Pre-installation blower door measurement at 50 Pascals pressure differential (CFM50_{pre})
- Post-installation blower door measurement at 50 Pascals pressure differential (CFM50_{post})

For greater accuracy, the following variables could additionally be collected:

- Central cooling presence
- Building type (single family or multifamily)

ENERGY CODES AND STANDARDS

This characterization is code-agnostic; however, implementers should comply with any and all local code requirements concerning air sealing standards.

²³⁴ Sherman, M.H. "Estimation of Infiltration from Leakage and Climate Indicators". *Energy and Buildings*, 10 (1987). Vermont is in zone 2, where N_0 varies between 17-19. A conservative value of 19 is assumed, consistent with New York TRM v11.0. Assumes average building height of 1.5 stories (height correction factor of 0.9), normal shielding (correction factor of 1.0), and normal leakage (correction factor of 1.0). $N = 19 \times 0.9 \times 1.0 \times 1.0 = 17.1$.

²³⁵ Illinois TRM v12.0. As recommended in Navigant 'ComEd Effective Useful Life Research Report', May 2018.

²³⁶ Efficiency Vermont TRM Program Year 2023, HPwES 2.0 Airsealing. No reference given.

3.2.2 BUILDING SHELL INSULATION

CHS Measure ID: RE_ENVE_INSU

Market Sector: Residential

End Use: Envelope

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Weatherization

Applicable Baseline Fuels: Natural gas, propane, fuel oil #2, electricity, wood, kerosene

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves adding insulation to building shell assemblies to reduce conductive heat loss to the outside. It is a Retrofit measure in which the baseline is the thermal resistance of the assembly prior to the installation and the proposed condition is the thermal resistance of the structure after the installation. This characterization may be applied to sloped ceiling, attic, above-grade walls, and below-grade walls. This characterization calculates CO₂e savings on a per square foot basis from actual pre- and post- R-values for insulation alone.

Baseline Conditions

The baseline is the R-value of the assembly prior to the retrofit. The assembly may have some existing insulation or none.

Proposed Conditions

The proposed condition is the R-value of the assembly after the retrofit. This characterization does not require a minimum level of insulation following the retrofit.

ELIGIBILITY CRITERIA

At a minimum, the interior space must be mechanically heated and maintained continuously at typical comfort temperatures.

DECARBONIZATION SUMMARY

Table 76 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Central A/C presence is unknown/not collected
- Heating efficiencies per Table 77
- Building type (single family or multifamily) is unknown/not collected

Table 76. Example Residential Building Shell Insulation CO2e Reductions

| Assembly Type | Heating System Type | Fuel | R-Value of Insulation Alone | | Lifetime CO2e Reductions per SF, Thermal [g/ft²] | Lifetime CO2e Reductions per SF, Total [g/ft²] | Lifetime Credits Per SF |
|--------------------------------------|---------------------|-------------|-----------------------------|----------|--|--|-------------------------|
| | | | Baseline | Proposed | | | |
| Attic, Standard Wood Framing | Boiler | Oil | None | R-49 | 114,627 | 115,337 | 0.1146 |
| | | Propane | None | R-49 | 95,742 | 96,414 | 0.0957 |
| | | Natural Gas | None | R-49 | 87,944 | 88,646 | 0.0879 |
| | | Kerosene | None | R-49 | 114,902 | 115,612 | 0.1149 |
| | Furnace | Oil | None | R-49 | 118,821 | 119,556 | 0.1188 |
| | | Propane | None | R-49 | 95,742 | 96,414 | 0.0957 |
| | | Natural Gas | None | R-49 | 80,459 | 81,104 | 0.0805 |
| | | Kerosene | None | R-49 | 119,106 | 119,841 | 0.1191 |
| | Heat Pump | Electric | None | R-49 | 6,693 | 6,898 | 0.0067 |
| | Baseboard | Electric | None | R-49 | 21,953 | 22,561 | 0.0220 |
| Pellet Stove | Wood | None | R-49 | 45,160 | 46,016 | 0.0452 | |
| Unknown | Unknown | None | R-49 | 94,711 | 95,413 | 0.0947 | |
| Exterior Wall, Standard Wood Framing | Boiler | Oil | None | R-15 | 45,777 | 46,061 | 0.0458 |
| | | Propane | None | R-15 | 38,235 | 38,503 | 0.0382 |
| | | Natural Gas | None | R-15 | 35,121 | 35,401 | 0.0351 |
| | | Kerosene | None | R-15 | 45,887 | 46,170 | 0.0459 |
| | Furnace | Oil | None | R-15 | 47,452 | 47,745 | 0.0475 |
| | | Propane | None | R-15 | 38,235 | 38,503 | 0.0382 |
| | | Natural Gas | None | R-15 | 32,132 | 32,389 | 0.0321 |
| | | Kerosene | None | R-15 | 47,566 | 47,859 | 0.0476 |
| | Heat Pump | Electric | None | R-15 | 2,673 | 2,755 | 0.0027 |
| | Baseboard | Electric | None | R-15 | 8,767 | 9,010 | 0.0088 |
| | Pellet Stove | Wood | None | R-15 | 18,035 | 18,377 | 0.0180 |
| | Unknown | Unknown | None | R-15 | 37,823 | 38,104 | 0.0378 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$\Delta\text{CO2e}_{\text{thermal}}$ = Total annual carbon dioxide equivalent emissions reductions in grams [g] = $\Delta\text{CO2e}_{\text{heat}}$

Annual Clean Heat Credits = $\Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$

CreditValue = 1 credit/tonneCO2e

1,000,000 = Grams per metric ton

$\Delta\text{CO2e}_{\text{heat}}$ = CO2e emissions reductions [g] from reducing heating energy

If primary heating fuel is known:

$$\text{Oil: } \Delta\text{CO2e}_{\text{heat}} = \Delta\text{E}_{\text{hl}} / \eta_{\text{heat}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \Delta\text{CO2e}_{\text{heat}} = \Delta\text{E}_{\text{hl}} / \eta_{\text{heat}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: } \Delta\text{CO2e}_{\text{heat}} = (\Delta\text{E}_{\text{hl}} / \eta_{\text{heat}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Kerosene: } \Delta\text{CO2e}_{\text{heat}} = \Delta\text{E}_{\text{hl}} / \eta_{\text{heat}} \times (\text{CI}_{\text{kerosene}} + \text{CI}'_{\text{kerosene}})$$

$$\text{Wood: } \Delta\text{CO2e}_{\text{heat}} = \Delta\text{E}_{\text{hl}} / \eta_{\text{heat}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})$$

$$\text{Electricity: } \Delta\text{CO2e}_{\text{heat}} = (\Delta\text{E}_{\text{hl}} / \eta_{\text{heat}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

η_{heat} = Heating system efficiency, dependent on fuel and system type²³⁷:

Table 77. Residential Deemed Heating System Efficiencies

| System Type | Fuel | Heating Efficiency (η_{heat}) |
|-------------|-------------------------|---|
| Boiler | Oil | 0.85 |
| | Propane | 0.90 |
| | Natural gas | 0.86 |
| | Kerosene | 0.85 |
| Furnace | Oil | 0.82 |
| | Propane | 0.90 |
| | Natural gas | 0.94 |
| | Kerosene | 0.82 |
| Heat Pump | Electric | 3.28 |
| Baseboard | Electric | 1.00 |
| Other | Pellet stove | 0.70 |
| | Newer EPA woodstove | 0.60 |
| | Catalytic woodstove | 0.50 |
| | Non-catalytic woodstove | 0.40 |
| | Outdoor wood boiler | 0.25 |
| | Open hearth fireplace | 0.10 |
| | Propane stove | 0.65 |

If primary heating fuel is unknown:

²³⁷ Efficiencies for fossil fuel systems and heat pumps are sourced from NMR Group, *2020 Vermont Single Family Existing Homes Baseline Study*, with the exception of propane furnaces and kerosene furnaces and boilers. Propane furnaces and the “Other” category are sourced from the *2023 Efficiency Vermont TRM*. Kerosene furnaces and boilers are assumed to have the same efficiency as oil furnaces and boilers, respectively.

$$\Delta\text{CO}_2e_{\text{heat}} = (\% \text{Oil} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}}) / \eta_{\text{ave,oil}}) + (\% \text{LP} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}}) / \eta_{\text{ave,LP}}) + (\% \text{NG} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{NG}} / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times \Delta E_{\text{hl}} \times \text{CI}_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + (\% \text{Wood} \times \Delta E_{\text{hl}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})) / \eta_{\text{ave,wood}}$$

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 78)²³⁸

$\eta_{\text{ave,fuel}}$ = Average heating efficiency for each fuel type [dimensionless] (see Table 78)²³⁹

Table 78. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |
| Wood | 8% | 1% | 7% | 0.53 |

$$\Delta E_{\text{hl}} = \text{Reduction in heating load [MJ]} = ((1/R_{\text{pre}} - 1/R_{\text{post}}) \times A_{\text{ins}} \times \text{HDH} \times \text{Adj}_{\text{heat}}) \times 0.00106$$

HDH = Heating degree hours [°F hr], dependent on structure being treated (see below)²⁴⁰

| Structure | HDH [°F hr] |
|------------------------------|-------------|
| Flat attic or sloped ceiling | 127,961.3 |
| Exterior walls | |
| Basement walls | 99,194.6 |

Adj_{heat} = Heating adjustment factor to reconcile this simplified algorithm with evaluation bill analysis results = 0.55 [dimensionless].²⁴¹

Non-Thermal Sector CO2e Impacts:

$$\Delta\text{CO}_2e_{\text{cool}} = \text{CO}_2e \text{ reductions [g]} \text{ from decreased cooling energy} = (\Delta E_{\text{cl}} / \eta_{\text{cool}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cl}} = \text{Reduction in cooling load [MJ]} = (\% \text{Cool} \times (1/R_{\text{pre}} - 1/R_{\text{post}}) \times A_{\text{ins}} \times \text{CDH} \times \text{Adj}_{\text{cool}}) \times 0.00106$$

²³⁸ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the “unknown” building type category by weighting according to the population of each building type in the respective studies.

²³⁹ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

²⁴⁰ NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, statewide mean values for each system type/fuel from Appendix A, except propane furnace efficiency carried forward from *Efficiency Vermont TRM Program Year 2023*, HPwES 2.0 Insulation: Attic and/or Basement.

²⁴¹ *Efficiency Vermont TRM Program Year 2023*, HPwES 2.0 Insulation: Attic and/or Basement, page 302, footnote 5.

%Cool = Presence of central cooling.²⁴²

| Central Cooling? | %Cool |
|--------------------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 7% |
| Unknown, Multifamily | 6% |
| Unknown, Building Type Unknown | 6.9% |

Adj_{cool} = Cooling adjustment factor to account for people not always operating their air-conditioning systems when the outside temperature is greater than 75 °F = 0.75 [dimensionless].²⁴³

CDH = Cooling degree hours [°F hr] = 6,619.²⁴⁴

η_{cool} = Cooling system efficiency = 3.72.²⁴⁵

ΔCO2e_{fan} = CO2e reductions [g] from decreased furnace fan or boiler pump energy = (ΔE_{fan} × CI_{elec})/(1-TDL_{elec})

ΔE_{fan} = Reduction in furnace fan or boiler pump energy [MJ]

If heating fuel is known:

$$\Delta E_{fan} = \%Fossil \times \Delta E_{hl} / \eta_{heat} \times F_e$$

If heating fuel is unknown:

$$\Delta E_{fan} = \%Fossil \times ((\%Oil \times \Delta E_{hl} / \eta_{ave,oil}) + (\%LP \times \Delta E_{hl} / \eta_{ave,LP}) + (\%NG \times \Delta E_{hl} / \eta_{ave,NG}) + (\%Elec \times \Delta E_{hl} / \eta_{ave,elec}) + (\%Wood \times \Delta E_{hl} / \eta_{ave,wood})) \times F_e$$

%Fossil = Presence of fossil-fuel furnace or boiler.

| Fossil Fuel System? | %Fossil |
|--------------------------------|---------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 85% |
| Unknown, Multifamily | 76% |
| Unknown, Building Type Unknown | 84% |

²⁴² Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

²⁴³ Energy Center of Wisconsin, Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research, 2008, page 31.

²⁴⁴ Efficiency Vermont TRM Program Year 2023, ERV/HRV. “Based on analysis of TMY data with 70 °F base temperature. See the 'Weather data' sheet of ERV_HRV_Analysis_2022.xlsx for more details.”

²⁴⁵ Calculated from statewide mean SEER = 12.7 of central air conditioner in VT from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 88: Central Air Conditioner Efficiency (SEER). COP = SEER / 3.412.

F_e = Furnace/boiler fan/pump energy as a percentage of annual fuel consumption = 3.14%.²⁴⁶

Common Inputs:

R_{pre} = Pre-installation R-value [(ft² °F hr)/Btu] of assembly, derived from tables below. For alternate construction types, refer to ASHRAE 90.1 Appendix A.

R_{post} = Post-installation R-value [(ft² °F hr)/Btu] of assembly, derived from tables below. For alternate construction types, refer to ASHRAE 90.1 Appendix A.²⁴⁷

Table 79. Residential Insulation: Assembly R-Factors for Attic Roofs with Wood Joists

| Rated R-Value of Insulation Alone | Overall R-Factor For Entire Assembly (R_{pre} , R_{post}) |
|--|---|
| Wood-Framed Attic, Standard Framing | |
| None | R-1.6 |
| R-11 | R-11.0 |
| R-13 | R-12.3 |
| R-19 | R-18.9 |
| R-30 | R-29.4 |
| R-38 | R-37.0 |
| R-49 | R-47.6 |
| R-60 | R-58.8 |

Table 80. Residential Insulation: Assembly R-Factors for Wood-Frame Walls

| Framing Type and Spacing Width (Actual Depth) | Cavity Insulation R-Value: Rated | Overall R-Factor For Entire Base Assembly | Overall R-Factor for Assembly of Base Wall Plus Continuous Insulation (Uninterrupted by Framing) (R_{pre} , R_{post}) | | | | |
|---|----------------------------------|---|---|--------|--------|--------|--------|
| | | | Rated R-Value of Continuous Insulation | | | | |
| | | | R-1 | R-2 | R-3 | R-4 | R-5 |
| Wood Studs at 16 in. on Center | | | | | | | |
| 3.5 in. depth | None | R-3.4 | R-4.5 | R-5.5 | R-6.6 | R-7.6 | R-8.6 |
| | R-11 | R-10.4 | R-11.5 | R-12.7 | R-13.7 | R-14.7 | R-15.9 |
| | R-13 | R-11.2 | R-12.5 | R-13.5 | R-14.7 | R-15.9 | R-16.9 |
| | R-15 | R-12.0 | R-13.3 | R-14.5 | R-15.6 | R-16.7 | R-17.9 |
| 5.5 in. depth | R-19 | R-14.9 | R-16.1 | R-17.2 | R-18.5 | R-19.6 | R-20.8 |
| | R-21 | R-15.9 | R-17.2 | R-18.5 | R-19.6 | R-20.8 | R-22.2 |
| + R-10 headers | R-19 | R-15.9 | R-16.9 | R-18.2 | R-19.2 | R-20.4 | R-21.3 |
| | R-21 | R-16.9 | R-18.2 | R-19.6 | R-20.4 | R-21.7 | R-22.7 |

²⁴⁶ Illinois TRM v12.0. “ F_e is not one of the AHRI certified ratings provided for residential furnaces, but can be reasonably estimated from a calculation based on the certified values for fuel energy (E_f in MMBTU/yr) and E_{ae} (kWh/yr). An average of a 300 record sample (non-random) out of 1495 was 3.14%.”

²⁴⁷ Insulation tables are derived from ASHRAE 90.1-2016 Normative Appendix A.

| R-6 | R-7 | R-8 | R-9 | R-10 | R-11 | R-12 | R-13 | R-14 | R-15 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| R-9.6 | R-10.6 | R-11.6 | R-12.7 | R-13.7 | R-14.7 | R-15.6 | R-16.7 | R-17.9 | R-18.9 |
| R-16.9 | R-17.9 | R-18.9 | R-20.0 | R-20.8 | R-21.7 | R-22.7 | R-23.8 | R-25.0 | R-26.3 |
| R-17.9 | R-18.9 | R-20.0 | R-21.3 | R-22.2 | R-23.3 | R-24.4 | R-25.0 | R-26.3 | R-27.0 |
| R-18.9 | R-20.0 | R-21.3 | R-22.2 | R-23.3 | R-24.4 | R-25.6 | R-26.3 | R-27.8 | R-28.6 |
| R-21.7 | R-22.7 | R-23.8 | R-25.0 | R-26.3 | R-27.0 | R-27.8 | R-29.4 | R-30.3 | R-31.3 |
| R-23.3 | R-24.4 | R-25.6 | R-26.3 | R-27.8 | R-28.6 | R-29.4 | R-31.3 | R-32.3 | R-33.3 |
| R-22.2 | R-23.3 | R-24.4 | R-25.6 | R-26.3 | R-27.8 | R-28.6 | R-29.4 | R-30.3 | R-32.3 |
| R-23.8 | R-25.0 | R-26.3 | R-27.0 | R-28.6 | R-29.4 | R-30.3 | R-31.3 | R-32.3 | R-33.3 |

Table 81. Residential Insulation: Assembly R-Factors for Below-Grade Mass Walls

| Depth, in. | Framing Type | Rated R-Value of Insulation Alone | | | | | | | |
|---|--------------|-----------------------------------|-------|-------|-------|-------|--------|--------|--------|
| | | R-0 | R-2 | R-4 | R-6 | R-8 | R-10 | R-12 | R-14 |
| Effective Value if Continuous Insulation Uninterrupted by Framing (Includes Gypsum Board) | | | | | | | | | |
| | None | R-0.5 | R-2.5 | R-4.5 | R-6.5 | R-8.5 | R-10.5 | R-12.5 | R-14.5 |
| Effective Value if Insulation is Installed in Cavity Between Framing (Includes Gypsum Board) | | | | | | | | | |
| 1.5 | Wood | R-1.3 | R-2.4 | R-3.8 | R-4.9 | R-5.8 | R-6.5 | R-7.1 | NA |
| 3.5 | Wood | R-1.4 | R-2.6 | R-4.4 | R-6.0 | R-7.4 | R-8.7 | R-9.8 | R-10.9 |
| 5.5 | Wood | R-1.4 | R-2.6 | R-4.6 | R-6.4 | R-8.1 | R-9.6 | R-11 | R-12.4 |

| R-16 | R-18 | R-20 | R-22 | R-24 |
|--------|--------|--------|--------|--------|
| R-16.5 | R-18.5 | R-20.5 | R-22.5 | R-24.5 |
| NA | NA | NA | NA | NA |
| R-11.8 | R-12.6 | R-13.4 | R-14.1 | R-14.8 |
| R-13.6 | R-14.7 | R-15.8 | R-16.8 | R-17.8 |

A_{ins} = Area in square feet of insulation applied, from application.

0.00106 = MJ per BTU.

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

Lifetime for attic and sloped ceiling insulation is 30 years.

Lifetime for exterior wall insulation is 30 years.

Lifetime for basement insulation is 15 years.²⁴⁸

MEASURE COST

Measure costs of \$3.5/sq ft is assumed for attic insulation.

Measure costs of \$6.0/sq ft is assumed for sloped ceiling insulation.

Measure costs of \$3,000 per job is assumed for basement insulation.

Measure costs of \$2/sq ft is assumed for wall insulation.²⁴⁹

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Heating fuel type
- Heating system type
- Total square feet of insulation installed (A_{ins})
- Insulation location (attic/ceiling, exterior walls, basement wall)
- Framing type
- Pre- R-value of insulation alone
- Post- R-value of insulation alone

For greater accuracy, the following variables could additionally be collected:

- Central cooling presence
- Building type (single family or multifamily)

ENERGY CODES AND STANDARDS

N/A

²⁴⁸ Efficiency Vermont TRM Program Year 2023, HPwES 2.0 Insulation: Attic and/or Basement, HPwES 2.0 Insulation: Exterior Walls.

²⁴⁹ Ibid.

3.3 DOMESTIC HOT WATER

3.3.1 HEAT PUMP WATER HEATER

CHS Measure ID: RE_DOHW_HPWH

Market Sector: Residential

End Use: Domestic Hot Water

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves installation of a Heat Pump Water Heater (HPWH) to provide domestic hot water (DHW) in a residential application. Heat pump water heaters efficiently heat water by transferring heat through a vapor compression cycle instead of combusting fuel.

This characterization includes indirect space heating impacts as a result of the HPWH.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical water heater consuming a representative mix of oil, natural gas, propane, and electricity. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is an installed HPWH.

ELIGIBILITY CRITERIA

To qualify, the installed HPWH must be a NEEA-certified Residential HPWH meeting at least Tier 1 Cool Climate Efficiency (CCE):²⁵⁰

Table 82. NEEA Residential HPWH Minimum CCE Requirements

| Tier | Minimum CCE |
|--------|-------------|
| Tier 1 | 2.0 |

²⁵⁰ NEEA Advanced Water Heating Specification Version 8.1. July 15, 2024. <https://neea.org/img/documents/Advanced-Water-Heating-Specification.pdf>

| Tier | Minimum CCE |
|--------|-------------|
| Tier 2 | 2.3 |
| Tier 3 | 2.6 |
| Tier 4 | 3.0 |
| Tier 5 | 3.5 |

This characterization is intended for fuel switching scenarios. Electric water heaters are only considered as a baseline component when the baseline water heater fuel is not collected.

DECARBONIZATION SUMMARY

Table 83 provides estimated lifecycle decarbonization ranges for example baseline and proposed conditions over the effective useful life of the measure. These estimates are not inclusive of all eligible possibilities; other values may be calculated from the following algorithms.

Assumptions:

- Average baseline water heater efficiencies per Table 84
- Average space heating efficiencies per Table 85
- Tier 1 Residential HPWH, $CCE_{HPWH} = 2.0$
- Building type (single family or multifamily) is unknown/not collected

Table 83. Example Residential Heat Pump Water Heater CO₂e Reductions

| Baseline Water Heating Fuel | Proposed Equipment | Space Heating Fuel | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------------------|--------------------|--------------------|---|--|------------------|
| Oil | HPWH Tier 1 | Oil | 8,876,954 | 8,876,954 | 8.9 |
| | | Propane | 9,201,205 | 9,201,205 | 9.2 |
| | | Natural Gas | 9,597,872 | 9,597,872 | 9.6 |
| | | Electricity | 11,635,819 | 11,635,819 | 11.6 |
| | | Wood | 10,742,268 | 10,742,268 | 10.7 |
| | | Unknown | 9,435,956 | 9,435,956 | 9.4 |
| Propane | HPWH Tier 1 | Oil | 7,318,305 | 7,318,305 | 7.3 |
| | | Propane | 7,642,557 | 7,642,557 | 7.6 |
| | | Natural Gas | 8,039,223 | 8,039,223 | 8.0 |
| | | Electricity | 10,077,170 | 10,077,170 | 10.1 |
| | | Wood | 9,183,619 | 9,183,619 | 9.2 |
| | | Unknown | 7,877,308 | 7,877,308 | 7.9 |
| Natural Gas | HPWH Tier 1 | Oil | 5,852,112 | 5,852,112 | 5.9 |
| | | Propane | 6,176,364 | 6,176,364 | 6.2 |

| Baseline Water Heating Fuel | Proposed Equipment | Space Heating Fuel | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
|-----------------------------|--------------------|--------------------|--|-------------------------------------|------------------|
| | | Natural Gas | 6,573,030 | 6,573,030 | 6.6 |
| | | Electricity | 8,610,977 | 8,610,977 | 8.6 |
| | | Wood | 7,717,426 | 7,717,426 | 7.7 |
| | | Unknown | 6,411,115 | 6,411,115 | 6.4 |
| Unknown | HPWH Tier 1 | Oil | 2,845,937 | 2,845,937 | 2.8 |
| | | Propane | 3,170,189 | 3,170,189 | 3.2 |
| | | Natural Gas | 3,566,855 | 3,566,855 | 3.6 |
| | | Electricity | 5,604,802 | 5,604,802 | 5.6 |
| | | Wood | 4,711,251 | 4,711,251 | 4.7 |
| | | Unknown | 3,404,940 | 3,404,940 | 3.4 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}} + \Delta\text{CO2e}_{\text{heat}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HPWH}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline water heater}$$

If baseline water heater fuel is known:

$$\text{Oil: } \Delta\text{CO2e}_{\text{heat}} = Q_{\text{load}} / \text{EF}_{\text{ave,oil}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \Delta\text{CO2e}_{\text{heat}} = Q_{\text{load}} / \text{EF}_{\text{ave,LP}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: } \Delta\text{CO2e}_{\text{heat}} = Q_{\text{load}} / \text{EF}_{\text{ave,LP}} \times \text{CI}_{\text{NG}} / (1 - \text{TDL}_{\text{NG}})$$

If baseline water heater fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil}_{\text{WH}} \times Q_{\text{load}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{EF}_{\text{ave,oil}}) + ((\% \text{LP}_{\text{WH}} \times Q_{\text{load}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \text{EF}_{\text{ave,LP}}) + ((\% \text{NG}_{\text{WH}} \times Q_{\text{load}} \times \text{CI}_{\text{NG}}) / \text{EF}_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec}_{\text{WH}} \times Q_{\text{load}} \times \text{CI}_{\text{elec}}) / \text{EF}_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$\%Oil_{WH}$, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 84)²⁵¹

EF_{ave} = Baseline water heater average efficiency by fuel [dimensionless]. Assumes approximate 4:1 ratio of storage units to instantaneous units based on 2020 Single Family Baseline Study.²⁵²

Table 84. Vermont Water Heating Fuel Mix and Average Efficiency, Residential Buildings

| Water Heating Fuel | $\%Fuel_{wh}$ | Average Water Heater Efficiency ($EF_{ave, fuel}$) |
|--------------------|---------------|--|
| Oil | 9% | 0.71 |
| Propane (LP) | 24% | 0.71 |
| Natural Gas (NG) | 23% | 0.71 |
| Electricity | 43% | 1.34 |

$$CO2e_{HPWH} = \text{Annual } CO2e \text{ emissions [g] from heat pump water heater} = (Q_{load} / CCE_{HPWH} \times Cl_{elec}) / (1 - TDL_{elec})$$

CCE_{HPWH} = NEEA HPWH Cool Climate Efficiency (CCE) rating. Use actual or assume minimum CCE based on tier. See Table 82.

$\Delta CO2e_{heat}$ = Change in CO2e emissions [g] due to impact of heat pump water heater on space heating load. Heat pump water heaters produce an ambient cooling effect which results in an increase in space heating load, which reduces the overall CO2e reductions.

If primary space heating fuel is known:

$$\text{Oil: } \Delta CO2e_{heat} = (\Delta E_{hl} / \eta_{ave, oil}) \times (Cl_{oil} + Cl'_{oil})$$

$$\text{Propane: } \Delta CO2e_{heat} = (\Delta E_{hl} / \eta_{ave, LP}) \times (Cl_{LP} + Cl'_{LP})$$

$$\text{Natural Gas: } \Delta CO2e_{heat} = (\Delta E_{hl} / \eta_{ave, NG}) \times (Cl_{NG} / (1 - TDL_{NG}))$$

$$\text{Electricity: } \Delta CO2e_{heat} = (\Delta E_{hl} / \eta_{ave, elec}) \times (Cl_{elec} / (1 - TDL_{elec}))$$

$$\text{Wood: } \Delta CO2e_{heat} = (\Delta E_{hl} / \eta_{ave, wood}) \times (Cl_{wood} + Cl'_{wood})$$

If primary space heating fuel is unknown:

$$\Delta CO2e_{heat} = ((\%Oil_{SH} \times \Delta E_{hl} \times (Cl_{oil} + Cl'_{oil})) / \eta_{ave, oil}) + ((\%LP_{SH} \times \Delta E_{hl} \times (Cl_{LP} + Cl'_{LP})) / \eta_{ave, LP}) + ((\%NG_{SH} \times \Delta E_{hl} \times Cl_{NG}) / \eta_{ave, NG}) / (1 - TDL_{NG}) + ((\%Elec_{SH} \times \Delta E_{hl} \times Cl_{elec}) / \eta_{ave, elec}) / (1 - TDL_{elec}) + ((\%Wood_{SH} \times \Delta E_{hl} \times (Cl_{wood} + Cl'_{wood})) / \eta_{ave, wood})$$

²⁵¹ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study.

²⁵² Based on minimum efficiency requirements in 10 CFR 430.32(d)(1). Electric efficiency is weighted-average of storage units and instantaneous units with weighting from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 103. Stand-alone storage water heaters are 55% compared to instantaneous water heaters at 12% of the system type mix.

%Oil_{SH}, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 85)²⁵³

$\eta_{ave,oil}$, etc. = Average heating efficiency for each fuel type [dimensionless] (see Table 85)²⁵⁴

Table 85. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Space Heating Fuel | Building Type | | | Average Space Heating Efficiency ($\eta_{ave,fuel}$) |
|--------------------|---------------|-------------|---------|--|
| | Single Family | Multifamily | Unknown | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |
| Wood | 8% | 1% | 7% | 0.53 |

$$\Delta E_{hl} = \text{Space heating load change} = -(Q_{load} \times IF) / CCE_{HPWH}$$

IF = Interactive factor, portion of HPWH ambient cooling impact that results in increased space heating = 0.542.²⁵⁵

Non-Thermal Sector CO2e Impacts: None

Common Inputs

Q_{load} = Annual water heating load [MJ] = 9,536.²⁵⁶

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

²⁵³ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline. The water heating data in the 2020 Vermont Multifamily Residential Baseline Study was deemed insufficient for deriving multifamily-specific water heating fuel mix and average efficiency. An average EF of 0.67 was assumed for oil storage water heaters, sourced from *EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case* (<https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf>). An average EF of 0.55 was assumed for tankless coil water heaters per engineering judgement.

²⁵⁴ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

²⁵⁵ 2023 Vermont Tier III TRM Characterizations, HPWH. “Based on bin analysis of annual heating hours for Burlington, VT using TMY3 data: 4484 / 8760 = 51.2%. Tier III trm-analysis-res-hpwh-nea-spec-2021.xlsx.”

²⁵⁶ 2023 Vermont Tier III TRM Characterizations, HPWH. 2649 kWh x 3.6 MJ/kWh = 9536 MJ. “Average annual DHW heat input for Vermont homes, derived from metered data for homes on CVPS Rate 3: Off-Peak Water Heating rate. See QDHW in Tier III trm-analysis-res-hpwh-nea-spec-2021.xlsx.”

The expected measure life is assumed to be 12 years.²⁵⁷

MEASURE COST

The assumed full retrofit cost of installation is below.²⁵⁸

| HPWH Tank Size [gal] | Installed Cost |
|----------------------|------------------------|
| ≤ 55 | \$2,087 |
| > 55 | \$2,820 ²⁵⁹ |

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- Cool Climate Efficiency of proposed heat pump water heater (CCE_{HPWH}) or Tier
- Fuel source of existing water heater

For increased accuracy, the following variable may optionally be tracked:

- Existing space heating system fuel

ENERGY CODES AND STANDARDS

Minimum efficiencies for residential water heaters are prescribed in 10 CFR 430.32.

Heat pump water heaters must conform to the NEEA Advanced Water Heating Specification to use this characterization.

²⁵⁷ Efficiency Vermont TRM 2023, HPWH. "NREL, National Residential Efficiency Measure Database Lifetime of Heat Pump measures. Please see files in Referenced Documents. Current link: <https://remdb.nrel.gov/measures.php?gld=6&ctld=270>"

²⁵⁸ Efficiency Vermont TRM 2023, HPWH. "Full cost is based on average Installed cost from NEEP Phase 3 Incremental Cost Study Data. See sheet "NEEP Raw Cost Data" & related pivot table in "Misc Calcs" of Analysis file for a data summary. For the raw data source, please see file "NEEP_ImprovedHPWaterHeaters_Incremental Costs_2016.xlsx", Installed Costs Table (NEEP 2016)."

²⁵⁹ Efficiency Vermont TRM 2023, HPWH. "Average Full Cost Heat Pump Water Heater for 60, 66 & 80 gallon capacity categories (NEEP 2016)."

3.3.2 LOW FLOW FAUCET AERATOR

CHS Measure ID: RE_DOHW_LFFA

Market Sector: Residential

End Use: Domestic Hot Water

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Grid Electricity

Decision/Action Type: Retrofit, MOP:New Construction

Program Delivery Type: Direct Install, RNC, Free Products, Dropship

MEASURE DESCRIPTION

This measure relates to the installation of low flow faucet aerators in single family and multifamily bathroom and kitchen faucet fixtures. Low flow aerators reduce the volume of hot water consumed and thus the thermal energy needed to heat it.

This measure may be installed through one of the following mechanisms:

- Residential new construction program
- Direct install implementation
- Free giveaways
- Dropship: product is ordered by building owner or implementer and drop-shipped to the site for self-installation. The program delivery agent shall verify the installation with the owner and reserve the right to inspect the installation.

Baseline Conditions

Retrofit: Existing bath or kitchen faucet aerator rated at 2.2 GPM.²⁶⁰

New Construction: New standard flow rate faucet aerator rated at 1.5 GPM.²⁶¹

Additionally, two options are presented for the existing water heater fuel impacts:

1. hypothetical water heater consuming a representative mix of oil, natural gas, propane, and electricity is assumed. This option is suitable for free giveaways.
2. Water heater fuel impacts are calculated based on the actual water heater fuel. This option is suitable for direct install, new construction and dropship implementations.

Proposed Conditions

Direct Install, Giveaways, and Dropship: Faucet aerator rated at 1.0 GPM for bathroom faucets and 1.5 GPM for kitchen faucets.

²⁶⁰ Existing faucets are assumed to comply with the federal standard which is 2.2 GPM at 60 psi. 10 CFR § 430.32.

²⁶¹ New construction faucets are assumed to comply with the Vermont state standard for faucets which is 1.5 GPM at 60 psi. 9 V.S.A. § 2795.14. The Vermont standard took effect on 7/1/2020.

ELIGIBILITY CRITERIA

For Direct Install, Free Products, and Dropship programs, the qualifying efficient flow rate for faucet aerators must be 1.0 GPM for bathroom and 1.5 GPM for kitchen. For RNC, the aerator must be WaterSense-labeled (<https://www.epa.gov/watersense>).

DECARBONIZATION SUMMARY

Table 86 provides lifecycle CO₂e reductions for eligible existing and proposed conditions over the expected useful life of the measure.

Assumptions:

- Average water heating fuel mix in Table 87
- Water heater efficiencies per Table 87
- Building type (single family or multifamily) is unknown/not collected

Table 86. Example Residential Low Flow Faucet Aerator CO₂e Reductions

| Program Delivery Type | Faucet Type | Baseline Aerator | Proposed Aerator | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------------|-------------|------------------|------------------|---|--|------------------|
| Direct Install | Kitchen | 2.2 GPM | 1.5 GPM | 213,044 | 213,044 | 0.2130 |
| | Bath | 2.2 GPM | 1.0 GPM | 36,339 | 36,339 | 0.0363 |
| New Construction | Kitchen | 1.5 GPM | 1.3 GPM | 5,313 | 5,313 | 0.0053 |
| | Bath | 1.5 GPM | 1.3 GPM | 415 | 415 | 0.0004 |
| Free Products | Kitchen | 2.2 GPM | 1.5 GPM | 132,087 | 132,087 | 0.1321 |
| | Bath | 2.2 GPM | 1.0 GPM | 22,530 | 22,530 | 0.0225 |
| Dropship | Kitchen | 2.2 GPM | 1.5 GPM | 191,739 | 191,739 | 0.1917 |
| | Bath | 2.2 GPM | 1.0 GPM | 32,705 | 32,705 | 0.0327 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector Decarbonization Impacts:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

²⁶² Efficiency Vermont Technical Reference Manual. 2023. Average flow rate of products on the WaterSense Labeled Products list as of October 18, 2022.

1,000,000 = Grams per metric ton.

$\Delta\text{CO2e}_{\text{direct}}$ = Annual CO2e reduction [g] due to equipment replacement

If water heater fuel is known:

$$\text{Oil: } \Delta\text{CO2e}_{\text{direct}} = (\Delta E_{\text{whl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{RE}_{\text{oil}}$$

$$\text{Propane: } \Delta\text{CO2e}_{\text{direct}} = (\Delta E_{\text{whl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{RE}_{\text{LP}}$$

$$\text{Natural Gas: } \Delta\text{CO2e}_{\text{direct}} = ((\Delta E_{\text{whl}} \times \text{CI}_{\text{NG}}) / \text{RE}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Electricity: } \Delta\text{CO2e}_{\text{direct}} = ((\Delta E_{\text{whl}} \times \text{CI}_{\text{elec}}) / \text{RE}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

If water heater fuel is unknown:

$$\Delta\text{CO2e} = (\% \text{Oil} \times \Delta E_{\text{whl}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \text{RE}_{\text{oil}} + (\% \text{LP} \times \Delta E_{\text{whl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \text{RE}_{\text{LP}} + (\% \text{NG} \times \Delta E_{\text{whl}} \times \text{CI}_{\text{NG}}) / \text{RE}_{\text{NG}} / (1 - \text{TDL}_{\text{NG}}) + (\% \text{Elec} \times \Delta E_{\text{whl}} \times \text{CI}_{\text{elec}}) / \text{RE}_{\text{elec}} / (1 - \text{TDL}_{\text{elec}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's water heating fuel mix (see Table 87)²⁶³

RE_{oil} etc. = Average water heater recovery efficiency by fuel type (see Table 87)²⁶⁴

Table 87. Vermont Water Heating Fuel Mix and Average Recovery Efficiency, Residential Buildings

| Water Heating Fuel | %Fuel | Recovery Efficiency (RE _{fuel}) |
|--------------------|-------|---|
| Oil | 9% | 0.83 |
| Propane (LP) | 24% | 0.83 |
| Natural Gas | 23% | 0.83 |
| Electricity | 43% | 1.71 |

$$\Delta E_{\text{whl}} = \text{Reduction in water heating load [MJ]} = ((\text{GPM}_{\text{Base}} \times \text{Throttle}_{\text{Base}} - \text{GPM}_{\text{Low}} \times \text{Throttle}_{\text{Low}}) \times (\text{Minutes/Person/Day}) \times (\text{People/Household}) \times (\text{Days/Year}) \times \text{DR} / (\text{Faucets/Home}) \times 8.3 \times (\text{T}_{\text{Faucet}} - \text{T}_{\text{inlet}}) \times \text{ISR}) \times 0.00106$$

GPM_{Base} = Flow rate of existing faucet aerator = 2.2 GPM for retrofit; 1.5 GPM for new construction

GPM_{Low} = Flow rate of low flow faucet aerator

= 1.3 GPM for New Construction

= 1.0 GPM (bathroom) and 1.5 GPM (kitchen) for Direct Install, Free Products and Dropship

²⁶³ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study.

²⁶⁴ Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 5, 6, 18, and 19.

$\text{Throttle}_{\text{Base}}$ = Percentage of full-throttle flow rate for baseline faucet = 83% ²⁶⁵

$\text{Throttle}_{\text{Low}}$ = Percentage of full-throttle flow rate for low flow faucet = 95% ²⁶⁶

Minutes/Person/Day = Average length of faucet use per person = 1.6 (bathroom); 4.5 (kitchen)²⁶⁷

People/Household = Average number of people per household = 2.30 ²⁶⁸

Days/Year = Days the faucet is used per year = 365

DR = Percentage of water that flows down the drain and is not collected in a sink or basin = 50% (bathroom); 70% (kitchen)²⁶⁹

Faucets/Home = Average number of faucet fixtures per household = 2.83 (SF bathroom); 1.5 (MF bathroom); 1.0 (kitchen); 2.70 (Unknown building type bathroom); 1.0 (Unknown building type kitchen)²⁷⁰.

T_{Faucet} = Mixed water temperature (°F) of hot water coming from faucet = 86°F (bathroom); 93°F (kitchen)²⁷¹

T_{inlet} = Inlet water temperature (°F) of water entering the household = 51.8°F²⁷²

²⁶⁵ Efficiency Vermont Technical Reference Manual. 2023. Schultdt, Marc, and Debra Tachibana, "Energy Related Water Fixture Measurements: Securing the Baseline for Northwest Single Family Homes. 2008 ACEEE Summer Study on Energy Efficiency in Buildings," 2008, page 1-265.

²⁶⁶ Ibid.

²⁶⁷ Efficiency Vermont Technical Reference Manual. 2023. Cadmus and Opinion Dynamics, for the Michigan Evaluation Working Group, "Showerhead and Faucet Aerator Meter Study Memorandum," June 2013, page 11, Table 7.

²⁶⁸ Efficiency Vermont Technical Reference Manual. 2023. Weighted average household size of owner-occupied versus renter-occupied housing units ((70.8% * 2.41) + (29.2% * 2.04)) based on 2015-2019 American Community Survey 5-Year Estimates for Vermont. See reference file US Census_2019_ACS_5YR_DP04_VT.csv.

²⁶⁹ Efficiency Vermont Technical Reference Manual. 2023. Because faucet usages are at times dictated by volume (for example, filling a sink to wash dishes), only usage that would allow water to go straight down the drain will provide savings. DR values are from Navigant Consulting, Inc. for the Ontario Energy Board, "Measures and Assumptions for Demand Side Management Planning, Appendix C: Substantiation Sheets," April 16, 2009, pages C-57 and C-61. DR values weighted by typical number of kitchen faucets (1 faucet) and bath faucets (2 faucets) in a household: (1/3 * 0.50) + (2/3 * 0.70) = 0.63.

Additional explanation of DR logic: During continuous flow of the system, when faucet flow time is equal (LFFA vs Baseline), savings are achieved. However, during batch flow (i.e. filling sink to X gallons) since time is not equal between the two scenarios, (timeLFFA > timeBaseline) we would not see savings related to draw on WH / water consumption. DR represents frequency of continuous flow events.

²⁷⁰ Illinois Technical Reference Manual. V12.0. September 2023. Effective January 2024. 5.4.4 Low Flow Faucet Aerators. Values for unknown building types are based on 90%/10% weighting for single family/multifamily building populations from 2020 Vermont single family and multifamily baseline studies.

²⁷¹ Ibid.

²⁷² Efficiency Vermont Technical Reference Manual. 2023. Average value for Burlington, Montpelier, Rutland, and Springfield, VT from U.S. DOE Standard Building America DHW Schedules, May 2014. Values found on Weather Inputs sheet on spreadsheet.

<http://energy.gov/eere/buildings/downloads/building-america-standard-dhw-schedules>

ISR = In-service rate, the percentage of incentivized units actually installed ²⁷³

Table 88. Low Flow Faucet Aerator ISRs

| Product Delivery Type | ISR |
|-----------------------|------|
| Direct Install | 100% |
| New Construction | 100% |
| Free Products | 62% |
| Dropship | 90% |

8.3 = Specific heat of water, the amount of energy needed to raise 1 gal of water by 1 °F [BTU/(gal °F)]

0.00106 = MJ per BTU

Non-Thermal Sector CO2e Impacts: None

Common Inputs:

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life of installed equipment is estimated to be 10 years.²⁷⁴

MEASURE COST

Direct Install: Combined labor and material costs. Default is \$13 if actual is unknown.

New Construction: Incremental material cost is \$6.

Free Products and Dropship: The measure cost for free giveaways and the dropship program is the actual program cost of a new aerator. Default = \$2 if actual is unknown.²⁷⁵

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

Direct Install, New Construction, Dropship:

- Aerator flow: 1.0, 1.3, or 1.5 GPM (GPM_{Low})

²⁷³ Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 12, 13.

²⁷⁴ Efficiency Vermont Technical Reference Manual. 2023. Measure lifetime from California DEER. See file DEER2014-EUL-table-update_2014-02-05.xlsx.

²⁷⁵ Efficiency Vermont Technical Reference Manual. 2023. See footnotes 21-23.

- Water heater fuel

Free Giveaways:

- Aerator flow: 1.0, 1.3, or 1.5 GPM (GPM_{Low})

ENERGY CODES AND STANDARDS

The baseline assumption for new construction is assumed to be the state standard which took effect on 7/1/2020²⁷⁶.

- 9 V.S.A. § 2795.14: maximum faucet flow rate is 1.5 GPM at 60 psi

The baseline assumption for existing buildings is assumed to be the federal standard.

- 10 CFR § 430.32: maximum faucet flow rate is 2.2 GPM at 60 psi

For RNC, the installed aerator must meet the US EPA's WaterSense criteria.

²⁷⁶ "Vermont 2018". Appliance Standards Awareness Project, <https://appliance-standards.org/state-legislation/vermont-2018>.

3.3.3 LOW FLOW SHOWERHEAD

CHS Measure ID: RE_DOHW_LFSH

Market Sector: Residential

End Use: Domestic Hot Water

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Grid Electricity

Decision/Action Type: Retrofit, MOP:New Construction

Program Delivery Type: Direct Install, RNC, Free Products, Dropship

MEASURE DESCRIPTION

This measure relates to the installation of low flow showerheads in single family and multifamily homes. Low flow showerheads reduce the volume of hot water consumed and thus the thermal energy needed to heat it.

This measure may be installed through one of the following mechanisms:

- Direct install implementation
- Residential new construction program
- Free giveaways
- Dropship: product is ordered by building owner or implementer and drop-shipped to the site for self-installation. The program delivery agent shall verify the installation with the owner and reserve the right to inspect the installation.

Baseline Conditions

Retrofit: Existing showerhead rated at 2.5 GPM.²⁷⁷

New Construction: New standard flow rate showerhead rated at 2.0 GPM.²⁷⁸

Proposed Conditions

Direct Install, Giveaways, and Dropship: Low flow showerhead rated at 1.5 GPM.²⁷⁹

New Construction: Showerhead rated at 1.8 GPM²⁸⁰

ELIGIBILITY CRITERIA

The qualifying efficient flow rate for showerheads is 1.5 GPM for Direct Install, Free Products, and Dropship programs. For New Construction, the showerhead must be WaterSense-labeled (<https://www.epa.gov/watersense>).

²⁷⁷ Existing showerheads are assumed to comply with the federal standard which is 2.5 GPM at 80 psi. 10 CFR § 430.32

²⁷⁸ New construction showerheads are assumed to comply with the Vermont state standard for faucets which is 2.0 GPM at 80 psi. 9 V.S.A. § 2795.14. The Vermont standard took effect on 7/1/2020

²⁷⁹ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnote 10

²⁸⁰ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnote 11

DECARBONIZATION SUMMARY

Table 89 provides lifecycle CO₂e reductions for eligible existing and proposed conditions over the expected useful life of the measure.

Assumptions:

- Average water heating fuel mix in Table 90.
- Water heater efficiencies per Table 90.
- Building type is unknown/not collected

Table 89. Example Residential Low Flow Showerhead CO₂e Reductions

| Program Delivery Type | Baseline Showerhead | Proposed Showerhead | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------------------|---------------------|---------------------|---|--|------------------|
| Direct Install | 2.5 GPM | 1.5 GPM | 368,615 | 368,615 | 0.4 |
| New Construction | 2.0 GPM | 1.8 GPM | 73,723 | 73,723 | 0.1 |
| Free Products | 2.5 GPM | 1.5 GPM | 206,424 | 206,424 | 0.2 |
| Dropship | 2.5 GPM | 1.5 GPM | 331,753 | 331,753 | 0.3 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$

$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$

$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$

1,000,000 = Grams per metric ton.

$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g] due to equipment replacement}$

If water heater fuel is known:

Oil: $\Delta\text{CO}_2\text{e}_{\text{direct}} = (\Delta E_{\text{whl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / RE_{\text{oil}}$

Propane: $\Delta\text{CO}_2\text{e}_{\text{direct}} = (\Delta E_{\text{whl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / RE_{\text{LP}}$

Natural Gas: $\Delta\text{CO}_2\text{e}_{\text{direct}} = ((\Delta E_{\text{whl}} \times CI_{\text{NG}}) / RE_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$

Electricity: $\Delta\text{CO}_2\text{e}_{\text{direct}} = ((\Delta E_{\text{whl}} \times CI_{\text{elec}}) / RE_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$

If water heater fuel is unknown:

$$\Delta\text{CO}_2\text{e} = (\% \text{Oil} \times \Delta E_{\text{whl}} \times (\text{CI}_{\text{oil}} + \text{CI}_{\text{oil}})) / \text{RE}_{\text{oil}} + (\% \text{LP} \times \Delta E_{\text{whl}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \text{RE}_{\text{LP}} + (\% \text{NG} \times \Delta E_{\text{whl}} \times \text{CI}_{\text{NG}}) / \text{RE}_{\text{NG}} / (1 - \text{TDL}_{\text{NG}}) + (\% \text{Elec} \times \Delta E_{\text{whl}} \times \text{CI}_{\text{elec}}) / \text{RE}_{\text{elec}} / (1 - \text{TDL}_{\text{elec}})$$

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 90)²⁸¹

RE_{oil} etc. = Average water heater recovery efficiency by fuel type (see Table 90)²⁸²

Table 90. Vermont Water Heating Fuel Mix and Average Recovery Efficiency, Residential Buildings

| Water Heating Fuel | %Fuel | Recovery Efficiency (RE _{fuel}) |
|--------------------|-------|---|
| Oil | 9% | 0.83 |
| Propane (LP) | 24% | 0.83 |
| Natural Gas | 23% | 0.83 |
| Electricity | 43% | 1.71 |

$$\Delta E_{\text{whl}} = \text{Reduction in water heating load [MJ]} \\ = (((\text{GPM}_{\text{Base}} - \text{GPM}_{\text{Low}}) \times (\text{Minutes/Shower}) \times (\text{People/Household}) \times (\text{Showers/Person/Day}) \times (\text{Days/Year}) / (\text{Showerheads/Home}) \times 8.3 \times (\text{T}_{\text{Sh}} - \text{T}_{\text{inlet}}) \times \text{ISR}) \times 0.00106$$

GPM_{Base} = Flow rate of existing showerhead = 2.5 for early replacement; 2.0 GPM for new construction.

GPM_{Low} = Flow rate of low flow showerhead = 1.5 GPM for early replacement; 1.8 GPM for new construction

Minutes/Shower = Average shower length in minutes per person = 7.8 ²⁸³

People/Household = Average number of people per household = 2.30 ²⁸⁴

Showers/Person/Day = Number of showers per person per day = 0.6 ²⁸³

Days/Year = Days the showerhead is used per year = 365²⁸⁵

²⁸¹ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study.

²⁸² Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 5, 6, 18, and 19.

²⁸³ Cadmus and Opinion Dynamics, for the Michigan Evaluation Working Group, "Showerhead and Faucet Aerator Meter Study Memorandum," June 2013, page 11, Table 7.

²⁸⁴ Efficiency Vermont Technical Reference Manual. 2023. Weighted average household size of owner-occupied versus renter-occupied housing units ((70.8% * 2.41) + (29.2% * 2.04)) based on 2015-2019 American Community Survey 5-Year Estimates for Vermont. See reference file US Census_2019_ACS_5YR_DP04_VT.csv.

²⁸⁵ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197

Showerheads/Home = Average number of showerhead fixtures per household = 1.79 (SF existing)²⁸⁶; 1.30 (MF existing)²⁸⁷; (1.74 unknown)²⁸⁸; 2.1 GPM (RNC)²⁸⁹

T_{Sh} = Mixed water temperature (°F) of hot water coming from showerhead = 101°F²⁹⁰

T_{inlet} = Inlet water temperature (°F) of water entering the household = 51.8°F²⁹¹

ISR = In-service rate representing the number of units installed²⁹²

Table 91. Low Flow Showerhead ISRs

| Product Delivery Type | ISR |
|-----------------------|------|
| Direct Install | 100% |
| New Construction | 100% |
| Free Products | 56% |
| Dropship | 90% |

8.3 = Specific heat of water, the amount of energy needed to raise 1 gal of water by 1°F [BTU/(gal °F)]

0.00106 = BTU per MJ

Non-Thermal Sector CO2e Impacts: None

Common Inputs:

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life of installed equipment is estimated to be 10 years.²⁹³

²⁸⁶ Cadmus and Opinion Dynamics Showerhead and Faucet Aerator Meter Study Memorandum dated June 2013, directed to Michigan Evaluation Working Group.

²⁸⁷ Ibid.

²⁸⁸ Unknown number of showerheads estimated as weighted-average with 90%/10% weighting factors for single family and multifamily households, based on population sizes in 2020 Vermont Single Family Existing Homes Baseline Study and 2020 Vermont Multifamily Residential Baseline Study.

²⁸⁹ 2023 Efficiency Vermont TRM, Low Flow Showerhead. "Average number of low-flow showerheads from NMR Group, "Vermont Residential New Construction Baseline Study Analysis of On-Site Audits (Draft Report)," May 12, 2017, page 12. Low flow is defined in the RNC report as 2.5 GPM, which is the maximum flow rate established by the Energy Policy Act of 1992 (EPAAct). Since the saturation rate of low-flow showerheads is 98% for new homes in EVT territory (Table 8, page 13), EVT assumes 2.1 showerheads/home is a reasonable assumption for RNC. Please see NMR_VT RNC Baseline SF Onsite Report Draft_051217.docx"

²⁹⁰ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 16

²⁹¹ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 17

²⁹² Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnotes 12, 13.

²⁹³ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 21

MEASURE COST

Direct Install: Combined labor and material costs. Default is \$22 for a fixed showerhead and \$27 for a handheld model.

New Construction: Incremental material cost is \$6.

Free Products and Dropship: The measure cost for free giveaways and the dropship program is the actual program cost of a new showerhead. Default = \$4 if unknown.²⁹⁴

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

Direct Install, New Construction, Dropship:

- Showerhead flow: 1.5 GPM or 1.8 GPM (GPM_{Low})
- Water heater fuel

Free Giveaways:

- Showerhead flow: 1.5 GPM or 1.8 GPM (GPM_{Low})

ENERGY CODES AND STANDARDS

The baseline assumption for new construction is assumed to be the state standard which took effect on 7/1/2020²⁹⁵.

- 9 V.S.A. § 2795.14: maximum shower flow rate is 2.0 GPM at 80 psi

The baseline assumption for existing buildings is assumed to be the federal standard.

- 10 CFR § 430.32: maximum shower flow rate is 2.5 GPM at 80 psi

For New Construction, the installed showerhead must meet the US EPA's WaterSense criteria.

²⁹⁴ Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 198. See footnotes 22 – 25.

²⁹⁵ "Vermont 2018". Appliance Standards Awareness Project, <https://appliance-standards.org/state-legislation/vermont-2018>.

3.3.4 SOLAR WATER HEATER

CHS Measure ID: RE_DOHW_SOWH

Market Sector: Residential

End Use: Domestic Hot Water

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Fuel Oil #2, Natural Gas, Propane, Electricity

Decision/Action Type: MOP, Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of a residential solar water heater. These products use solar energy to heat domestic water directly, or indirectly via a non-freezing heat transfer fluid. The latter type is best suited for northern climates. Solar water heaters include a solar collector and storage tank with electric or fossil fuel backup heating.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical conventional water heater consuming a representative mix of oil, natural gas, propane, and electricity. This scenario is suitable for Downstream offerings in which the baseline water heater fuel is not collected.
2. A minimum efficiency oil, natural gas, propane, or electric water heater. This scenario is suitable for Downstream offerings in which the baseline water heater fuel is collected.

Proposed Conditions

The proposed condition is a solar water heater installation including a solar collector and storage tank with electric or fossil fuel backup heating.

ELIGIBILITY CRITERIA

The solar water heater must be OG-300 certified by the Solar Rating & Certification Corporation (ICC-SRCC).²⁹⁶

DECARBONIZATION SUMMARY

Table 92 provides lifecycle CO₂e reductions for example existing and proposed conditions over the expected useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

²⁹⁶ See <https://solar-rating.org> for certified product list.

Assumptions:

- Baseline and backup water heater fuels are the same
- Baseline water heater efficiency by fuel per Table 93

Table 92. Example Residential Solar Water Heater CO₂e Reductions

| Backup Fuel | SUEF Range | Assumed SUEF | Lifetime CO ₂ e Reductions, Thermal Sector [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-------------|----------------|--------------|---|--|------------------|
| Oil | 1.0 to < 1.5 | 1.25 | 17,249,869 | 17,249,869 | 17.2 |
| | 1.5 to < 2.0 | 1.75 | 20,877,817 | 20,877,817 | 20.9 |
| | 2 to < 2.5 | 2.25 | 22,893,344 | 22,893,344 | 22.9 |
| | 2.5 or greater | 3.00 | 24,656,930 | 24,656,930 | 24.7 |
| Natural Gas | 1.0 to < 1.5 | 1.25 | 10,672,003 | 10,672,003 | 10.7 |
| | 1.5 to < 2.0 | 1.75 | 13,486,597 | 13,486,597 | 13.5 |
| | 2 to < 2.5 | 2.25 | 15,050,261 | 15,050,261 | 15.1 |
| | 2.5 or greater | 3.00 | 16,418,466 | 16,418,466 | 16.4 |
| Propane | 1.0 to < 1.5 | 1.25 | 12,163,746 | 12,163,746 | 12.2 |
| | 1.5 to < 2.0 | 1.75 | 15,371,767 | 15,371,767 | 15.4 |
| | 2 to < 2.5 | 2.25 | 17,154,001 | 17,154,001 | 17.2 |
| | 2.5 or greater | 3.00 | 18,713,455 | 18,713,455 | 18.7 |
| Electricity | 1.0 to < 1.5 | 1.25 | 1,125,729 | 1,125,729 | 1.1 |
| | 1.5 to < 2.0 | 1.75 | 2,022,414 | 2,022,414 | 2.0 |
| | 2 to < 2.5 | 2.25 | 2,520,572 | 2,520,572 | 2.5 |
| | 2.5 or greater | 3.00 | 2,956,460 | 2,956,460 | 3.0 |
| Unknown | 1.0 to < 1.5 | 1.25 | 7,863,491 | 7,863,491 | 7.9 |
| | 1.5 to < 2.0 | 1.75 | 10,087,929 | 10,087,929 | 10.1 |
| | 2 to < 2.5 | 2.25 | 11,323,727 | 11,323,727 | 11.3 |
| | 2.5 or greater | 3.00 | 12,405,051 | 12,405,051 | 12.4 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g] due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{swh}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g] from baseline water heater}$$

If baseline water heater fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (Q_{\text{load}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \text{UEF}_{\text{min,oil}}$$

$$\text{Propane: CO2e}_{\text{base}} = (Q_{\text{load}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \text{UEF}_{\text{min,LP}}$$

$$\text{Natural Gas: CO2e}_{\text{base}} = (Q_{\text{load}} / \text{UEF}_{\text{min,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Electricity: CO2e}_{\text{base}} = (Q_{\text{load}} / \text{UEF}_{\text{min,elec}} \times CI_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

If baseline water heater fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil}_{\text{WH}} \times Q_{\text{load}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \text{UEF}_{\text{min,oil}}) + ((\% \text{LP}_{\text{WH}} \times Q_{\text{load}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \text{UEF}_{\text{min,LP}}) + ((\% \text{NG}_{\text{WH}} \times Q_{\text{load}} \times CI_{\text{NG}}) / \text{UEF}_{\text{min,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec}_{\text{WH}} \times Q_{\text{load}} \times CI_{\text{elec}}) / \text{UEF}_{\text{min,elec}}) / (1 - \text{TDL}_{\text{elec}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's water heating fuel mix (see Table 93)²⁹⁷

UEF_{min,oil}, etc. = Minimum water heater uniform energy factor (UEF) [dimensionless] by fuel (see Table 93). Based on CFR minimum efficiency requirements assuming 50 gallon storage tanks and medium draw pattern. Assumes approximate 4:1 ratio of storage units to instantaneous units based on 2020 Single Family Baseline Study.²⁹⁸

Table 93. Vermont Water Heating Fuel Mix and Minimum Heating Efficiency, Residential Buildings

| Water Heating Fuel | %Fuel _{wh} | Minimum Water Heater Efficiency (UEF _{min,fuel}) |
|--------------------|---------------------|--|
| Oil | 11% | 0.53 |
| Propane (LP) | 32% | 0.60 |
| Natural Gas | 15% | 0.60 |
| Electricity | 42% | 0.92 |

CO2e_{swh} = Annual CO2e emissions [g] from solar water heater

If backup water heater fuel is known:

$$\text{Oil: CO2e}_{\text{swh}} = (Q_{\text{load}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \text{SUEF}$$

$$\text{Propane: CO2e}_{\text{swh}} = (Q_{\text{load}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \text{SUEF}$$

$$\text{Natural Gas: CO2e}_{\text{swh}} = (Q_{\text{load}} / \text{SUEF} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Electricity: CO2e}_{\text{swh}} = (Q_{\text{load}} / \text{SUEF} \times CI_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

If backup water heater fuel is unknown:

²⁹⁷ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study.

²⁹⁸ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 103. Stand-alone storage water heaters are 55% compared to instantaneous water heaters at 12% of the system type mix.

$$CO2e_{SWH} = ((\%Oil \times Q_{load} \times (CI_{oil} + CI'_{oil})) / SUEF) + ((\%LP \times Q_{load} \times (CI_{LP} + CI'_{LP})) / SUEF) + ((\%NG \times Q_{load} \times CI_{NG}) / SUEF) / (1 - TDL_{NG}) + ((\%Elec \times Q_{load} \times CI_{elec}) / SUEF) / (1 - TDL_{elec})$$

SUEF = Solar Uniform Energy Factor rating of the solar water heater [dimensionless], as certified by ICC-SRCC.

Non-Thermal Sector CO2e Impacts: None

Common Inputs

Q_{load} = Annual water heating load [MJ] = 9,536.²⁹⁹

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

20 years³⁰⁰

MEASURE COST

- Retrofit: Use actual installed cost of SWH if available, or assume \$6,000 for planning purposes.³⁰¹
- MOP: Determine incremental cost of SWH compared to a conventional gas or electric storage water heater. Default value is \$4,731.³⁰²

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

Downstream programs:

- Solar water heater SUEF rating
- Backup fuel (oil, natural gas, propane, or electricity)
- Baseline water heater fuel (oil, natural gas, propane, or electricity)

²⁹⁹ 2022 Tier III TRM Characterizations, HPWH. 2649 kWh x 3.6 MJ/kWh = 9536 MJ. "Average annual DHW heat input for Vermont homes, derived from metered data for homes on CVPS Rate 3: Off-Peak Water Heating rate. See QDHW in Tier III trm-analysis-res-hpwh-nea-spec-2021.xlsx."

³⁰⁰ Act 56 Tier III Planning Tool PY2024_2_13_2024.xlsx.

³⁰¹ Installed cost of solar water heater is estimated to be \$6,000, midpoint of \$3,000 - \$9,000 range before tax credits and rebates. Source: <https://homeguide.com/costs/solar-water-heater-cost>, accessed August 9, 2024.

³⁰² Baseline water heater installed cost is estimated to \$2,087 - \$818 = \$1,269. Source: 2023 Efficient Vermont TRM, Heat Pump Water Heaters: "NEEP Emerging Technologies Incremental Cost Study Final Report, Table 3-34, pg 81. (2016). See sheet "NEEP Cost Summary" in the Analysis File. For Original Report see file "NEEP Incremental Cost Study FINAL_061016.pdf". " Solar water heater incremental cost = \$6,000 - \$1,269 = \$4,731.

ENERGY CODES AND STANDARDS

Eligible equipment must comply with the ICC 901/SRCC 300 standard.

3.4 HVAC

3.4.1 ADVANCED THERMOSTATS

CHS Measure ID: RE_HVAC_ADVT

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Electricity, Wood

Decision/Action Type: Retrofit, MOP:New Construction

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of an advanced thermostat to control a residential HVAC system. An advanced thermostat is capable of automatically establishing a schedule of temperature setpoints and automatic variations to better match HVAC system run times to meet occupant comfort requirements, resulting in energy savings. These schedules may be defaults, established through user interaction, and be changed manually at the device or remotely through a web or mobile app. Automatic variations to that schedule could be driven by local sensors and software algorithms, and/or through connectivity to an internet software service. Data triggers to automatic schedule changes might include, for example: occupancy/activity detection, arrival & departure of conditioned spaces, optimization based on historical or population-specific trends, weather data and forecasts.³⁰³

Baseline Conditions

The baseline for Retrofits is assumed to be a mix of programmable and manual thermostats.

The baseline for New Construction is assumed to be a programmable thermostat.

Proposed Conditions

The proposed condition is an advanced thermostat.

ELIGIBILITY CRITERIA

The criteria for this measure are established by replacement of a manual-only or programmable thermostat, with one that has the default enabled capability—or the capability to automatically—establish a schedule of temperature setpoints according to driving device inputs above and beyond basic time and temperature data of conventional programmable thermostats. This category of products and services is broad and rapidly advancing in regard to their capability, usability, and sophistication, but at a minimum must be capable of two-way

³⁰³ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 204

communication and exceed the typical performance of manual and conventional programmable thermostats through the automatic or default capabilities described above.³⁰⁴

This measure must be paired with one of the following system types: gas or oil furnace, combination furnace/central AC, gas or oil fossil-fuel boiler, or central air source or ground source heat pump.

DECARBONIZATION SUMMARY

Table 94 provides lifecycle CO₂e reductions for this measure across eligible heating fuels and Decision/Action Types over the effective useful life of this measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Central heat pump presence unknown
- Central A/C presence unknown
- Building type unknown
- Heating system input capacity defaults (see Table 97):
 - Retrofit: 67,307 Btu/h
 - New Construction: 40,237

Table 94. Example Residential Advanced Thermostat CO₂e Reductions

| Decision/Action Type | Heating Fuel | Lifetime CO ₂ e Reductions, Thermal [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|----------------------|--------------|--|--|------------------|
| Retrofit | Oil | 3,890,333 | 3,896,644 | 3.9 |
| | Propane | 3,438,438 | 3,444,749 | 3.4 |
| | Natural Gas | 3,012,541 | 3,018,852 | 3.0 |
| | Electricity | 1,329,365 | 1,335,676 | 1.3 |
| | Wood | 1,759,318 | 1,765,630 | 1.8 |
| | Unknown | 3,188,074 | 3,194,385 | 3.2 |
| New Construction | Oil | 1,515,949 | 1,547,299 | 1.5 |
| | Propane | 1,339,859 | 1,371,209 | 1.3 |
| | Natural Gas | 1,173,899 | 1,205,249 | 1.2 |
| | Electricity | 518,015 | 549,365 | 0.5 |
| | Wood | 685,555 | 716,905 | 0.7 |
| | Unknown | 1,242,299 | 1,273,649 | 1.2 |

³⁰⁴ Ibid.

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$\Delta\text{CO2e}_{\text{thermal}}$ = Total annual carbon dioxide equivalent emissions reductions in grams [g] = $\Delta\text{CO2e}_{\text{heat}}$

Annual Clean Heat Credits = $\Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$

CreditValue = 1 credit/tonneCO2e

1,000,000 = Grams per metric ton

$\Delta\text{CO2e}_{\text{heat}}$ = CO2e emissions reductions from reducing heating energy

If heating fuel is known:

Oil: $\Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{heat}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$

Propane: $\Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{heat}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$

Natural Gas: $\Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{heat}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$

Wood: $\Delta\text{CO2e}_{\text{heat}} = \Delta E_{\text{heat}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}})$

Electricity: $\Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{heat}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$

If heating fuel is unknown:

$\Delta\text{CO2e}_{\text{heat}} = (\% \text{Oil} \times \Delta E_{\text{heat}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) + (\% \text{LP} \times \Delta E_{\text{heat}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) + (\% \text{NG} \times \Delta E_{\text{heat}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}}) + (\% \text{Elec} \times \Delta E_{\text{heat}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}}) + (\% \text{Wood} \times \Delta E_{\text{heat}} \times (\text{CI}_{\text{wood}} + \text{CI}'_{\text{wood}}))$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 95)³⁰⁵

Table 95. Vermont Primary Heating Fuel Mix, Residential Buildings

| Heating Fuel | Building Type | | |
|------------------|---------------------|-------------------|---------------|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel |
| Oil | 45% | 5% | 41% |
| Propane (LP) | 17% | 5% | 16% |
| Natural Gas (NG) | 23% | 66% | 27% |
| Electricity | 6% | 23% | 8% |
| Wood | 8% | 1% | 7% |

ΔE_{heat} = Heating energy reduction [MJ] = $(\text{EFLH}_{\text{heat}} \times \text{Btu}_{\text{in,heat}} \times \text{SF}_{\text{heat}} \times (1 - \% \text{CHP})) \times 0.00106$

³⁰⁵ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the "unknown" building type category by weighting according to the population of each building type in the respective studies.

$EFLH_{heat}$ = Estimate of annual household equivalent full load heating hours for heating equipment

Table 96. Residential Advanced Thermostat $EFLH_{heat}$

| Decision/Action Type | $EFLH_{heat}$ ³⁰⁶ |
|----------------------|------------------------------|
| Retrofit | 878 |
| New Construction | 855 |

$Btuh_{in,heat}$ = Input Capacity of Heating System in Btu/h controlled by thermostat.

For fossil fuel system, use rated if known, or defaults in Table 97.

For heat pump system, $Btuh_{in,heat} = Btuh_{out,heat} / COP_{heat}$ where $Btuh_{out,heat}$ = rated heating output capacity at 47 °F in Btu/h. Use rated output capacity if known, or defaults in Table 98. COP_{heat} = Heating coefficient of performance (COP) of heat pump = 3.28.³⁰⁷

For wood heater, use defaults in Table 97 or calculate from rated capacity: $Btuh_{in,heat} = Btuh_{out,heat} / \eta_w$ where η_w = wood heating efficiency. Assume $\eta_w = 65\%$ if unknown.³⁰⁸

Table 97. Residential Advanced Thermostat: Input Capacity of Fossil Heating System

| Household Type | $Btuh_{in,heat}$ ³⁰⁹ | |
|----------------|---------------------------------|------------------|
| | Retrofit | New Construction |
| Single Family | 70,979 | 41,532 |
| Multifamily | 34,260 | 28,585 |
| Unknown | 67,307 | 40,237 |

Table 98. Residential Advanced Thermostat: Heating Output Capacity of Heat Pump System

| Household Type | $Btuh_{out,heat}$ ³¹⁰ | |
|----------------|----------------------------------|------------------|
| | Retrofit | New Construction |
| Single Family | 80,124 | 44,510 |
| Multifamily | 76,874 | 30,354 |
| Unknown | 79,800 | 43,094 |

³⁰⁶ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats.

³⁰⁷ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. The mean HSPF of Heat Pump Systems is 11.2.

³⁰⁸ Efficiency Vermont TRM Program Year 2023, Central Wood Pellet Boilers and Furnaces. “Efficiency of existing wood heating systems based on professional judgment.”

³⁰⁹ Calculated using assumptions from Efficiency Vermont TRM Program Year 2023, Advanced Thermostats (Capacity = Gas Heating Consumption × 1,000,000/ $EFLH_{heat}$ × %Controlled)

³¹⁰ Calculated using assumptions from Efficiency Vermont TRM Program Year 2023, Advanced Thermostats (Capacity = Elec Heating Consumption × 3412/ $EFLH_{heat}$ × %Controlled × COP_{heat}) where $COP_{heat} = 3.72$.

SF_{heat} = Assumed savings factor for total household heating energy consumption due to installation of advanced thermostat, including 0.79% additional savings for thermostat optimization services. See Table 102.

%CHP = Presence of central air source or ground source heat pump as the primary heating system. This variable is used to account for heat pump manufacturer recommendations to limit temperature setbacks during the heating season.³¹¹

| Central Heat Pump? | %CHP | |
|--------------------------------|----------|------------------|
| | Retrofit | New Construction |
| Yes | 100% | |
| No | 0% | |
| Unknown, Single Family | 3% | 11% |
| Unknown, Multifamily | 6% | 11% |
| Unknown, Unknown Building Type | 3.3% | 11% |

Non-Thermal Sector CO₂e Impacts:

$$\Delta\text{CO}_2\text{e}_{\text{cool}} = (\Delta E_{\text{cool}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cool}} = \text{Cooling energy reduction [MJ]} = \% \text{Cool} \times (\text{EFLH}_{\text{cool}} \times \text{Btu}_{\text{out,cool}} / \text{COP}_{\text{cool}} \times \text{SF}_{\text{cool}}) \times 0.00106$$

Btu_{out,cool} = Output cooling capacity of heat pump or AC in Btu/h

Table 99. Advanced Thermostat Capacity of AC Unit

| Household Type | Capacity [Btu/h] ³¹² |
|----------------|---------------------------------|
| Single Family | 37,200 |
| Multifamily | 18,542 |
| Unknown | 35,334 |

%Cool = Presence of central cooling system³¹³

³¹¹ Source: Table 58, NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study; Table 60, NMR Group, 2020 Vermont Single Family New Construction Baseline and Code Compliance Study; and Table 63, NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Because the sample size of multifamily new construction buildings was very small, single family new construction values were used as a proxy. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

³¹² Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 206, footnote 14,15

³¹³ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Because the sample size of multifamily new construction buildings was very small, single family new construction values were used as a proxy. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

Table 100. Percentage of Residential Customers with Central Cooling

| Central Cooling? | %Cool | |
|--------------------------------|----------|------------------|
| | Retrofit | New Construction |
| Yes | 100% | |
| No | 0% | |
| Unknown, Single Family | 7% | 41% |
| Unknown, Multifamily | 6% | 41% |
| Unknown, Unknown Building Type | 6.9% | 41% |

$EFLH_{cool}$ = Estimate of annual equivalent full load cooling hours for heat pump or air conditioner = 375.³¹⁴

COP_{cool} = Cooling coefficient of performance for air-conditioner or heat pump

Table 101. Residential Advanced Thermostat: Cooling COP

| Decision/Action Type | COP_{cool} |
|----------------------------------|--------------|
| Early Replacement ³¹⁵ | 3.72 |
| New Construction ³¹⁶ | 4.45 |

SF_{cool} = Assumed savings factor for total household cooling energy consumption due to installation of advanced thermostat, including 0.65% additional savings for thermostat optimization services. See Table 102.

Common Inputs

Table 102. Advanced Thermostat Savings Factors

| Decision/ Action Type | Building Type | Heating Savings Factor ³¹⁷ | Cooling Savings Factor ³¹⁸ |
|-----------------------|---------------|---------------------------------------|---------------------------------------|
| Early Replacement | Single Family | 7.6% | 8.5% |
| | Multifamily | 8.2% | 8.5% |
| | Unknown | 7.7% | 8.5% |
| New Construction | Either | 5.6% | 8.5% |

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

³¹⁴ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 206, footnote 3

³¹⁵ Calculated from statewide mean SEER = 12.7 of central air conditioner in VT from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 88: Central Air Conditioner Efficiency (SEER). $COP = SEER / 3.412$.

³¹⁶ Calculated from statewide mean SEER = 15.2 of central air conditioner in VT from NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study, Table 82: Central Air Conditioner Efficiency (SEER). $COP = SEER / 3.412$.

³¹⁷ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats.

³¹⁸ Ibid.

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

0.00106 = MJ per BTU.

MEASURE LIFE

The expected measure life of installed equipment is estimated to be 10 years.³¹⁹

MEASURE COST

For early replacement, measure costs, including labor and equipment, for installing an advanced thermostat is \$225. For new construction, the incremental cost between a programmable and advanced thermostat is assumed to be \$150.³²⁰

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Heating Fuel Type

For greater accuracy, the following variables could also be collected:

- Heating System Capacity
- Cooling System Capacity
- Presence of Central Cooling System

In addition, collecting the existing thermostat type would not affect the results but would create a dataset that could be used to inform future revisions to this measure.

ENERGY CODES AND STANDARDS

Not Applicable.

³¹⁹ Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 207

³²⁰ Ibid.

3.4.2 ADVANCED WOOD HEATING – CENTRAL PELLET SYSTEMS

CHS Measure ID: RE_HVAC_AWHC

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Advanced Wood Heating

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of advanced central wood pellet heating systems less than 340,000 Btu/h in existing residential buildings, displacing a fossil fuel system and serving as the primary heating system. Eligible systems include hydronic heater or forced air furnace systems with a full load efficiency of 85% or higher based on higher heating value (HHV), and an emissions rate of less than 0.08 lbs/MMBTU of fine particulate matter (less than 2.5 microns).

Baseline Conditions

The assumed baseline may be one of the following conditions:

3. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
4. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed system is a central pellet system with an assumed efficiency of 86% satisfying at least 90% of the building's heating load. The system is assumed to be installed according to manufacturer specifications and burn only pellets throughout its lifetime. It is assumed that the homeowner follows all manufacturer recommendations for regular cleaning to maintain the rated efficiency.

ELIGIBILITY CRITERIA

Eligible wood heating systems include all of the following characteristics:

- EPA-certified for pellet burning
- Full load efficiency \geq 85% (HHV) as certified by EPA
- PM_{2.5} emissions rate $<$ 0.08 lbs/MMBTU as certified by EPA
- Provides central heating and is the primary heating system

This characterization is intended for fossil fuel to advanced wood heating conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 103 provides estimated lifetime carbon reductions for example existing and proposed conditions. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Certified efficiency of new pellet system: 86%
- Baseline efficiencies per Table 104
- Pellet system meets 90% of the annual heating load
- Single Family building, existing heating capacity is 91,562 Btu/h³²¹

Table 103. Example Residential Central Pellet System CO₂e Reductions

| Baseline Heating Fuel | Existing Capacity [Btu/h] | Lifetime CO ₂ e reductions [g], Thermal Sector | Lifetime CO ₂ e reductions [g], Total | Lifetime Credits |
|-----------------------|---------------------------|---|--|------------------|
| Natural Gas | 91,562 | 54,320,309 | 54,320,309 | 54.3 |
| Propane | | 72,337,762 | 72,337,762 | 72.3 |
| Fuel Oil #2 | | 85,260,942 | 85,260,942 | 85.3 |
| Unknown | | 66,716,665 | 66,716,665 | 66.7 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reductions [g] due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{pellet}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

³²¹ 2023 Vermont Tier III TRM. Average capacity of primary space heating systems installed in Vermont homes.

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - TDL_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - TDL_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - TDL_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 104)

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 104)

Table 104. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |
| Wood | 8% | 1% | 7% | 0.53 |

$$\text{CO2e}_{\text{pellet}} = \text{Annual CO2e emissions [g] due to pellet system operation} = (E_{\text{hl}} / \eta_{\text{pellet}}) \times (CI_{\text{pellet}} + CI'_{\text{wood}})$$

η_{pellet} = Rated pellet heating system efficiency = 86%.³²²

CI_{pellet} = Carbon intensity of wood pellets [g CO2e/MJ]

E_{hl} = Heating load served by the pellet system [MJ] = (%Pellet x Btuh x EFLH) x 0.00106

%Pellet = Percentage of annual heating load provided by pellet system³²³

| Decision / Action Type | %Pellet |
|------------------------|---------|
| Retrofit | 90% |

Btuh = Rated output capacity of pellet heater in Btu’s per hour [Btu/h]

EFLH = Heating equivalent full load hours

³²² Efficiency Vermont 2023 TRM. “Weighted average efficiency of qualified models available on Renewable Energy Resource Center, “Small Scale Renewable Energy Incentive Program.”

(SSREIP) Advanced Wood Pellet Heating System Eligible Equipment Inventory,” June 6, 2016.

³²³ Efficiency Vermont 2023 TRM. “Energy & Research Solutions, “Emerging Technologies Research Report,” (report prepared for the Regional Evaluation, Measurement, and Verification Forum, February 13, 2013): page 9-22.”

| Decision/Action Type | EFLH |
|-------------------------|-------|
| Retrofit ³²⁴ | 780.5 |

0.00106 = MJ per BTU.

Non-Thermal Sector CO₂e Impacts: None

Common Inputs

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is 18 years.³²⁵

MEASURE COST

| Decision/Action Type | Cost Type | Cost |
|-------------------------|-----------|----------|
| Retrofit ³²⁶ | Full | \$20,000 |

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- Output capacity (Btuh) in Btu’s per hour [Btu/h]
- Decision/Action Type: MOP or Retrofit
- Efficient equipment full load efficiency, HHV (η_{pellet})

³²⁴ Efficiency Vermont 2023 TRM. “Residential FLH for existing homes is a weighted average of FLH for boilers and furnances in existing homes. Boiler and furnace weightings are from NMR Group, “VT SF Existing Homes Onsite Report,” 2013, Table 5-4. FLH values were estimated by following a methodology outlined in the Uniform Methods Project using natural gas billing data provided by Vermont Gas Systems (VGS) for homes that participated in Efficiency Vermont’s Residential New Construction (RNC) program. Since capacity has not been collected through the Home Performance with ENERGY STAR program it was not possible to perform the analysis with a more appropriate data set for this program. For Existing Homes, the RNC data was limited to only those homes with annual gas consumption greater than 25kbtu/sq ft in an attempt to remove the high performance/ low load homes in RNC. See ‘VGS Usage Regression Work_04182017.xls’ for analysis.”

³²⁵ Midpoint of 12 – 25 year range for pellet stoves specified in EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case. <https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf>, accessed August 23, 2024.

³²⁶ Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers & Furnaces. “Pellet boiler installed cost from Energy & Research Solutions, “Emerging Technologies Research Report,” (report prepared for the Regional Evaluation, Measurement, and Verification Forum, February 13, 2013): page 9-2. Pellet furnace installed costs are assumed to be similar to pellet boiler costs.”

ENERGY CODES AND STANDARDS

All new wood heating appliances offered for sale in the US are required to meet New Source Performance Standards (NSPS)³²⁷ promulgated by the US EPA. The NSPS requires that appliances meet specified particulate matter emission limits, revised most recently in 2020. The NSPS does not prescribe minimum efficiencies but requires manufacturers to have the efficiency tested and certified by an accredited laboratory.

The EPA maintains a certified wood heater database where certified emissions and efficiency values are listed by make and model. (<https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.about>).

³²⁷ 40 CFR Part 60. <https://www.federalregister.gov/documents/2015/03/16/2015-03733/standards-of-performance-for-new-residential-wood-heaters-new-residential-hydronic-heaters-and>, accessed August 23, 2024.

3.4.3 ADVANCED WOOD HEATING – PELLET STOVES

CHS Measure ID: RE_HVAC_AWHS

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family

Decarbonization Pathways: Advanced Wood Heating

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the installation of wood pellet stoves in existing residential buildings. It is assumed that the stove supplements an existing space heating system and offsets a portion of the existing system's fuel consumption. To use this characterization, new stoves must have certified efficiencies and PM_{2.5} emissions rates of at least 70% and no more than 2.0 g/hr, respectively. (PM_{2.5} refers to "fine particles" having an aerodynamic diameter of 2.5 microns or less.)

Baseline Conditions

The assumed baseline may be one of the following conditions:

3. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
4. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed system is a new pellet stove at least 70% efficient supplementing an existing heating system. The system is assumed to be installed according to manufacturer specifications and burn only the fuel it is certified for throughout its lifetime. It is assumed that the homeowner follows all manufacturer recommendations for regular cleaning to maintain the rated efficiency.

ELIGIBILITY CRITERIA

Eligible wood heating systems must meet both of the following requirements as certified by the EPA (see <https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.about>):

- Efficiency ≥ 70%
- PM_{2.5} ≤ 2.0 g/hr

This characterization is intended for displacement of fossil fuel consumption by pellet stoves. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 105 provides estimated lifetime carbon reductions for example existing and proposed conditions. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Certified efficiency of new stove: 77%
- Stove offsets 64% of annual heating load
- Baseline heating efficiencies per Table 106
- Single Family building, existing heating capacity is 91,562 Btu/h

Table 105. Example Residential Pellet Wood Stove CO₂e Reductions

| Baseline Heating Fuel | Existing Capacity [Btu/h] | Lifetime CO ₂ e reductions [g], Thermal Sector | Lifetime CO ₂ e reductions [g], Total | Lifetime Credits |
|-----------------------|---------------------------|---|--|------------------|
| Natural Gas | 91,562 | 35,394,599 | 35,394,599 | 35.4 |
| Propane | | 48,207,010 | 48,207,010 | 48.2 |
| Fuel Oil #2 | | 57,396,827 | 57,396,827 | 57.4 |
| Unknown | | 44,209,785 | 44,209,785 | 44.2 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reductions [g]} \text{ due to wood stove operation} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{pellet}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g]} \text{ from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: } \text{CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \text{CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural gas: } \text{CO}_2\text{e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$CO2e_{base} = ((\%Oil \times E_{hl} \times (CI_{oil} + CI'_{oil})) / \eta_{ave,oil}) + ((\%LP \times E_{hl} \times (CI_{LP} + CI'_{LP})) / \eta_{ave,LP}) + ((\%NG \times E_{hl} \times CI_{NG}) / \eta_{ave,NG}) / (1 - TDL_{NG}) + ((\%Elec \times E_{hl} \times CI_{elec}) / \eta_{ave,elec}) / (1 - TDL_{elec}) + ((\%Wood \times E_{hl} \times (CI_{wood} + CI'_{wood})) / \eta_{ave,wood})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 106)

$\eta_{ave,fuel}$ = Average heating efficiency by fuel type [dimensionless] (see Table 106)

Table 106. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{ave,fuel}$) |
|------------------|---------------------|-------------------|---------------|---|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |
| Wood | 8% | 1% | 7% | 0.53 |

$$CO2e_{pellet} = \text{Annual } CO2e \text{ emissions [g] due to stove operation} = (E_{hl} / \eta_{eff}) \times (CI_{pellet} + CI'_{wood})$$

η_{eff} = Certified efficiency of new stove.³²⁸

| Stove Type | Efficiency (η_{eff}) |
|------------|-----------------------------|
| Pellet | 77% |

CI_{pellet} = Carbon intensity of wood pellets [g CO2e/MJ]

$$E_{hl} = \text{Wood stove heating load in megajoules [MJ]} = (\%Stove \times \text{Capacity} \times \text{EFLH}) \times 0.00106$$

%Stove = Percentage of annual heating load provided by stove, by type:

| Stove Type | %Stove |
|-----------------------|--------|
| Pellet ³²⁹ | 64% |

³²⁸ Average efficiency of new stoves meeting PM2.5 ≤ 2.0 and 70% efficiency requirements on EPA list of certified wood heaters as of August 2024.

³²⁹ 2023 Vermont Tier III TRM. "%stove for pellet stoves is calculating using: the percentage of primary (70%) versus supplemental (30%) pellet users in Vermont and the annual tons of pellets burned by primary (4.4) versus supplemental (3.3) pellet users from Vermont Department of Forests, Parks, and Recreation, "Vermont Residential Fuel Assessment for the 2014-2015 Heating Season," March 2016, pages 7-8; an average annual heat load of 80.832 MMBtu for Vermont homes (700 gallons/oil per year based on 2016 VT Tier III TAG agreement/84.2% oil heating system efficiency in existing VT homes); 77% stove efficiency based on data received by Efficiency Vermont on 08/21/2017 from the upcoming NMR Vermont Residential Market Assessment; and 16.4 MMBtu/ton heat content from the November 2016 VT Fuel Price Report. %stove is calculated as ((70% (4.4 tons/yr * 16.4 MMBtu/ton * 77% / 80.832)) + (30% (3.3 tons/yr * 16.4 MMBtu/ton * 77% / 80.832))). See %stove tab in file EVT_Pellet Wood Stove_Analysis_Aug 2018_v2.xlsx for calculation."

Capacity = Average capacity of primary space heating system installed in Vermont homes [Btu/h] = 91,562.³³⁰

EFLH = Heating equivalent full load hours = 780.5.³³¹

0.00106 = MJ per BTU

Non-Thermal Sector CO₂e Impacts: None

Common Inputs

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is 18 years.³³²

MEASURE COST

For retrofits, the measure cost is the total installed cost of the new stove:

| Stove Type | Stove Cost | Installation Cost | Other Costs* | Total Installed Cost |
|------------|------------|-------------------|--------------|----------------------|
| Pellet | \$3,366 | \$340 | \$694 | \$4,400 |

*Costs not included in "stove cost" or "installation cost," such as miscellaneous parts or recycling fees.

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- Efficient equipment full load efficiency, HHV (η_{eff})

For additional accuracy, the following variable should also be tracked:

³³⁰ 2023 Vermont Tier III TRM. "FLH and capacity values estimated by following a methodology outlined in the Uniform Methods Project using natural gas billing data provided by Vermont Gas Systems (VGS) for homes that participated in Efficiency Vermont's Residential New Construction (RNC) program. Since capacity has not been collected through the Home Performance with ENERGY STAR program it was not possible to perform the analysis with a more appropriate data set for this program. For Existing Homes, the RNC data was limited to only those homes with annual gas consumption greater than 25kBtu/sq ft in an attempt to remove the high performance/ low load homes in RNC. See 'VGS Usage Regression Work_04182017.xls' for analysis. For existing homes, final FLH and capacity values were calculated using boiler and furnace weightings from NMR Group, "VT SF Existing Homes Onsite Report," 2013, page 58, Table 5-4. For new construction, weightings are from NMR Group, "Vermont Residential New Construction Baseline Study Analysis of On-Site Audits (Draft Report)," May 12, 2017, page 47, Table 47."

³³¹ Efficiency Vermont 2023 TRM. "Residential FLH for existing homes is a weighted average of FLH for boilers and furnances in existing homes. Boiler and furnace weightings are from NMR Group, "VT SF Existing Homes Onsite Report," 2013, Table 5-4. FLH values were estimated by following a methodology outlined in the Uniform Methods Project using natural gas billing data provided by Vermont Gas Systems (VGS) for homes that participated in Efficiency Vermont's Residential New Construction (RNC) program. Since capacity has not been collected through the Home Performance with ENERGY STAR program it was not possible to perform the analysis with a more appropriate data set for this program. For Existing Homes, the RNC data was limited to only those homes with annual gas consumption greater than 25kBtu/sq ft in an attempt to remove the high performance/ low load homes in RNC. See 'VGS Usage Regression Work_04182017.xls' for analysis."

³³² Midpoint of 12 – 25 year range for pellet stoves specified in EIA – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case. <https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/appendix-a.pdf>, accessed August 23, 2024.

- Primary heating system capacity [Btu/h] (Capacity)

ENERGY CODES AND STANDARDS

All new wood heating appliances offered for sale in the US are required to meet New Source Performance Standards (NSPS)³³³ promulgated by the US EPA. The NSPS requires that appliances meet specified particulate matter emission limits, revised most recently in 2020. The NSPS does not prescribe minimum efficiencies but requires manufacturers to have the efficiency tested and certified by an accredited laboratory.

The EPA maintains a certified wood heater database where certified emissions and efficiency values are listed by make and model. (<https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.about>).

³³³ 40 CFR Part 60. <https://www.federalregister.gov/documents/2015/03/16/2015-03733/standards-of-performance-for-new-residential-wood-heaters-new-residential-hydronic-heaters-and>, accessed August 23, 2024.

3.4.4 AIR SOURCE HEAT PUMP – DUCTED, FULL DISPLACEMENT

CHS Measure ID: RE_HVAC_HPDP

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of centrally ducted, cold climate air source heat pumps in residential buildings, displacing a fossil fuel system and serving as the primary heating system. The heat pump is assumed to operate down to an outdoor temperature of -5°F to +5°F.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing central A/C presence and determine cooling impacts on a per site basis. If the home is confirmed to have an existing central A/C system, the algorithm assumes no cooling impacts. If there is no existing central A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing central A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont homes with existing central cooling systems.

Baseline Conditions

The assumed baseline may be one of the following conditions:

5. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
6. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is a NEEP-certified cold climate ducted air source heat pump serving as the primary heating source.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed system is a split system, ducted air source heat pump meeting NEEP efficiency standards for ducted central air conditioning heat pumps (SEER2 \geq 14.3, HSPF2 \geq 7.7, COP at 5 °F \geq 1.75 at maximum capacity operation)³³⁴
- Switchover temperature of 5 °F or lower
- Heat pump cooling capacity of < 65,000 Btu/h

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 107 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Heat pump meets NEEP minimum efficiency standards
- Existing central A/C presence is unknown

Table 107. Example Residential ASHP-Ducted-Full Displacement CO_{2e} Reductions

| Building Type | Baseline Heating Fuel | Lifetime CO _{2e} Reductions per Ton _R [g CO _{2e} /ton _R], Thermal Sector | Lifetime CO _{2e} Reductions per Ton _R [g CO _{2e} /ton _R], Total | Lifetime Credits per Ton _R |
|---------------|-----------------------|---|--|---------------------------------------|
| Single Family | Natural Gas | 26,214,192 | 25,970,885 | 26.2 |
| | Propane | 31,163,280 | 30,919,973 | 31.2 |
| | Fuel Oil #2 | 35,215,372 | 34,972,065 | 35.2 |
| | Unknown | 29,096,609 | 28,853,302 | 29.1 |
| Multifamily | Natural Gas | 26,214,192 | 25,968,269 | 26.2 |
| | Propane | 31,163,280 | 30,917,357 | 31.2 |
| | Fuel Oil #2 | 35,215,372 | 34,969,449 | 35.2 |
| | Unknown | 29,096,609 | 28,850,686 | 29.1 |
| Unknown | Natural Gas | 26,214,192 | 25,970,624 | 26.2 |
| | Propane | 31,163,280 | 30,919,711 | 31.2 |
| | Fuel Oil #2 | 35,215,372 | 34,971,803 | 35.2 |
| | Unknown | 29,096,609 | 28,853,040 | 29.1 |

³³⁴ NEEP Cold Climate Air Source Heat Pump Specification (Version 4.0). https://neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final_1.pdf, accessed August 15, 2024.

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HPheat}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 108)³³⁵

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 108)³³⁶

Table 108. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |

³³⁵ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the "unknown" building type category by weighting according to the population of each building type in the respective studies.

³³⁶ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{ave, fuel}$) |
|--------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Wood | 8% | 1% | 7% | 0.53 |

$$CO2e_{HPheat} = \text{Annual } CO2e \text{ emissions [g] due to heat pump heating operation} = (E_{hl} / (HSPF2/0.85) \times 3.412) \times Cl_{elec} / (1 - TDLelec)$$

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh]. Use actual or assume 7.7 if unknown.

0.85 = Conversion factor to convert HSPF2 to HSPF³³⁷

3.412 = Btu per Watt-hour. Used to convert HSPF [Btu/(Watt hour)] to COP [dimensionless]. COP = HSPF2/3.412.

$$E_{hl} = \text{Heating load served by the heat pump [MJ]} = (HCAP_{47F} \times EFLH_{heat}) \times 0.00106$$

HCAP_{47F} = Rated heating output capacity of heat pump at 47 °F in Btu's per hour [Btu/h]

EFLH_{heat} = Equivalent full load heating hours = 1,909 hours.³³⁸

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{HPcool} = \text{CO2e emissions impact [g] due to added cooling load} = (\Delta E_{cool} \times Cl_{elec}) / (1 - TDLelec)$$

$$\Delta E_{cool} = \text{Cooling energy impacts [MJ]} = -((1 - \%Cool) \times (CCAP \times EFLH_{cool}) / SEER2) \times 0.0036$$

%Cool = Presence of central cooling.³³⁹

| Central Cooling? | %Cool |
|--------------------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 7% |
| Unknown, Multifamily | 6% |
| Unknown, Building Type Unknown | 6.9% |

CCAP = Rated cooling output capacity of heat pump in Btu's per hour [Btu/h]

³³⁷ Illinois TRM v12.0. "Consortium for Energy Efficiency (CEE), Testing, Testing, M1, 2, 3, Transitioning to New Federal Minimum Standards, CEE Summer Program Meeting, August, 2022."

³³⁸ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source "EFLH analysis 2024-08-21" workbook.

³³⁹ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

SEER2 = Seasonal Energy Efficiency Rating2 (SEER2) for heat pump (cooling efficiency)
[Btu/Wh] = 14.3.

EFLH_{cool} = Equivalent full load cooling hours = 240 hours.³⁴⁰

0.0036 = MJ per Watt-hour.

Common Inputs

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 16 years.³⁴¹

MEASURE COST

The assumed full retrofit cost of ducted air source heat pumps is below³⁴²:

| Capacity (Btu/h) | Ducted |
|------------------|---------|
| 9,000 | \$1,517 |
| 12,000 | \$1,688 |
| 15,000 | \$1,803 |
| 18,000 | \$2,111 |
| 24,000 | \$3,240 |
| 30,000 | \$3,601 |
| 36,000 | \$4,461 |
| 42,000 | \$5,079 |
| 48,000 | \$5,498 |
| 54,000 | \$6,019 |
| 60,000 | \$7,532 |
| 66,000 | \$6,275 |
| 72,000 | \$6,491 |

³⁴⁰ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). “Residential EFLH Cooling is calculated in an analysis of heat pump metered data. The partial load of each heat pump is summed up through the heating season, and taken as an average across all units metered. This analysis can be found on the EFLH Calculator tab in the EVT_CCHP MOP and Retrofit_2018_.xlsx.”

³⁴¹ Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.”

³⁴² Vermont 2023 Act 56 Tier III TRM. “Analysis can be found on the Retrofit Cost tab of evt-centrally-ducted-ashp-analysis-Tier III 9 24 2019.xlsx. Mid-Atlantic Technical Reference Manual, version 7.0, May 2017.”

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity at 47°F of heat pump (HCAP_{47F}).
- Rated cooling capacity of heat pump (CCAP).
- Baseline heating fuel

For greater accuracy, the following variables could also be collected:

- Existing central A/C presence
- Building type (Single Family or Multifamily)

ENERGY CODES AND STANDARDS

NEEP Cold Climate Air Source Heat Pump Specification, Version 4.0.

3.4.5 AIR SOURCE HEAT PUMP – DUCTED, PARTIAL DISPLACEMENT

CHS Measure ID: RE_HVAC_HPDP

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of centrally ducted air source heat pumps in residential buildings that partially displace fossil fuel-based heating. The heat pump is assumed to serve as the primary heating system above approximately 35 °F; below this temperature, heating is provided by a fossil fuel system, either integrated with the heat pump or controlled separately.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing central A/C presence and determine cooling impacts on a per site basis. If the home is confirmed to have an existing central A/C system, the algorithm assumes no cooling impacts. If there is no existing central A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing central A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont homes with existing central cooling systems.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is an ENERGY STAR-certified ducted air source heat pump providing heating above an outdoor air temperature of approximately 35 °F. The heat pump is assumed to be oversized relative to the load at the switchover temperature.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed system is a split system, ducted air source heat pump meeting ENERGY STAR efficiency standards (SEER2 \geq 15.2, EER2 \geq 11.7, HSPF2 \geq 7.8)³⁴³.
- Heat pump is installed to supplement a fossil fuel system.
- Heat pump cooling capacity is < 65,000 Btu/h

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 109 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Heat pump meets ENERGY STAR minimum efficiency standards for split system heat pumps
- Existing central A/C presence is unknown

Table 109. Example Residential ASHP-Ducted-Partial Displacement CO₂e Reductions

| Building Type | Baseline Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Total | Lifetime Credits per Ton _R |
|---------------|-----------------------|--|---|---------------------------------------|
| Single Family | Natural Gas | 8,927,211 | 8,698,310 | 8.9 |
| | Propane | 10,609,901 | 10,381,000 | 10.6 |
| | Fuel Oil #2 | 11,987,612 | 11,758,711 | 12.0 |
| | Unknown | 9,907,233 | 9,678,332 | 9.9 |
| Multifamily | Natural Gas | 8,927,211 | 8,695,849 | 8.9 |
| | Propane | 10,609,901 | 10,378,539 | 10.6 |
| | Fuel Oil #2 | 11,987,612 | 11,756,250 | 12.0 |
| | Unknown | 9,907,233 | 9,675,871 | 9.9 |
| Unknown | Natural Gas | 8,927,211 | 8,698,064 | 8.9 |
| | Propane | 10,609,901 | 10,380,754 | 10.6 |
| | Fuel Oil #2 | 11,987,612 | 11,758,465 | 12.0 |
| | Unknown | 9,907,233 | 9,678,086 | 9.9 |

³⁴³ ENERGY STAR Program Requirements: Product Specification for Central Air Conditioner and Heat Pump Equipment: Eligibility Criteria Version 6.1 (Rev. January 2022). <https://www.energystar.gov/sites/default/files/2024-08/ENERGY%20STAR%20Version%206.1%20CACHP%20Final%20Specification%20and%20Partner%20Commitments%20Rev.%20January%202022.pdf>, accessed August 15, 2024.

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HPheat}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 110)³⁴⁴

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 110)³⁴⁵

Table 110. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |

³⁴⁴ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the "unknown" building type category by weighting according to the population of each building type in the respective studies.

³⁴⁵ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{ave, fuel}$) |
|--------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Wood | 8% | 1% | 7% | 0.53 |

$$CO2e_{HPheat} = \text{Annual } CO2e \text{ emissions [g] due to heat pump heating operation} = (E_{hl} / (HSPF2/0.85) \times 3.412) \times Cl_{elec} / (1 - TD_{L_{elec}})$$

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh]. Use actual or assume 7.8 if unknown.

0.85 = Conversion factor to convert HSPF2 to HSPF³⁴⁶

3.412 = Btu per Watt-hour. Used to convert HSPF [Btu/(Watt hour)] to COP [dimensionless]. COP = HSPF2/3.412.

$$E_{hl} = \text{Heating load served by the heat pump [MJ]} = (HF \times HCAP_{47F} \times EFLH_{heat}) \times 0.00106$$

HF = Heatload Factor, reduces EFLH to account for partial displacement. = 34%.³⁴⁷

HCAP_{47F} = Rated heating output capacity of heat pump at 47 °F in Btu's per hour [Btu/h]

EFLH_{heat} = Equivalent full load heating hours = 1,909 hours.³⁴⁸

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{HPcool} = \text{CO2e emissions impact [g] due to added cooling load} = (\Delta E_{cool} \times Cl_{elec}) / (1 - TD_{L_{elec}})$$

$$\Delta E_{cool} = \text{Cooling energy impacts [MJ]} = -((1 - \%Cool) \times (CCAP \times EFLH_{cool}) / SEER2) \times 0.0036$$

%Cool = Presence of central cooling.³⁴⁹

| Central Cooling? | %Cool |
|------------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 7% |

³⁴⁶ Illinois TRM v12.0. "Consortium for Energy Efficiency (CEE), Testing, Testing, M1, 2, 3, Transitioning to New Federal Minimum Standards, CEE Summer Program Meeting, August, 2022."

³⁴⁷ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Based on the ratio of EFLH for a partial displacement heat pump providing heat at outdoor temperatures of 35 °F and above to EFLH for a full displacement heat pump. Source: "EFLH analysis 2024-08-21" workbook.

³⁴⁸ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source "EFLH analysis 2024-08-21" workbook.

³⁴⁹ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

| | |
|--------------------------------|------|
| Unknown, Multifamily | 6% |
| Unknown, Building Type Unknown | 6.9% |

CCAP = Rated cooling output capacity of heat pump in Btu’s per hour [Btu/h]

SEER2 = Seasonal Energy Efficiency Rating2 (SEER2) for heat pump (cooling efficiency) [Btu/Wh] = 15.2.

EFLH_{cool} = Equivalent full load cooling hours = 240 hours.³⁵⁰

0.0036 = MJ per Watt-hour.

Common Inputs

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 16 years.³⁵¹

MEASURE COST

The assumed full retrofit cost of ducted air source heat pumps is below³⁵²:

| Capacity (Btu/h) | Ducted |
|------------------|---------|
| 9,000 | \$1,517 |
| 12,000 | \$1,688 |
| 15,000 | \$1,803 |
| 18,000 | \$2,111 |
| 24,000 | \$3,240 |
| 30,000 | \$3,601 |
| 36,000 | \$4,461 |
| 42,000 | \$5,079 |
| 48,000 | \$5,498 |
| 54,000 | \$6,019 |
| 60,000 | \$7,532 |
| 66,000 | \$6,275 |

³⁵⁰ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). “Residential EFLH Cooling is calculated in an analysis of heat pump metered data. The partial load of each heat pump is summed up through the heating season, and taken as an average across all units metered. This analysis can be found on the EFLH Calculator tab in the EVT_CCHP MOP and Retrofit_2018_.xlsx.”

³⁵¹ Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.”

³⁵² Vermont 2023 Act 56 Tier III TRM. “Analysis can be found on the Retrofit Cost tab of evt-centrally-ducted-ashp-analysis-Tier III 9 24 2019.xlsx. Mid-Atlantic Technical Reference Manual, version 7.0, May 2017.”

| | |
|--------|---------|
| 72,000 | \$6,491 |
|--------|---------|

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity at 47 °F of heat pump (HCAP_{47F}).
- Rated cooling capacity of heat pump (CCAP).

For greater accuracy, the following variables could also be collected:

- Backup heating fuel
- Existing central A/C presence
- Building type (Single Family or Multifamily)

ENERGY CODES AND STANDARDS

ENERGY STAR Product Specification for Central Air Conditioner and Heat Pump Equipment, Version 6.1.

3.4.6 AIR SOURCE HEAT PUMP – DUCTLESS, FULL DISPLACEMENT

CHS Measure ID: RE_HVAC_HPXF

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of ductless cold climate air source heat pumps (ccASHP) in residential buildings, displacing a fossil fuel system and serving as the primary heating system. The heat pump is assumed to operate down to an outdoor temperature of -5 °F – +5 °F.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing central A/C presence and determine cooling impacts on a per site basis. If the home is confirmed to have an existing central A/C system, the algorithm assumes no cooling impacts. If there is no existing central A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing central A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont homes with existing central cooling systems.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is a NEEP-certified cold climate ductless air source heat pump serving as the primary heating source.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed system is a split system, ductless air source heat pump meeting with NEEP efficiency standards for non-ducted heat pump split systems (SEER2 \geq 15, HSPF2 \geq 8.5. COP at 5 °F \geq 1.75 at maximum capacity operation)³⁵³
- Heat pump cooling capacity of < 65,000 Btu/h

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 111 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Heat pump meets NEEP minimum efficiency standards
- Existing central A/C presence is unknown

Table 111. Example Residential ASHP-Ductless-Full Displacement CO₂e Reductions

| Building Type | Baseline Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Total | Lifetime Credits per Ton _R |
|---------------|-----------------------|--|---|---------------------------------------|
| Single Family | Natural Gas | 26,348,942 | 26,116,989 | 26.3 |
| | Propane | 31,298,029 | 31,066,077 | 31.3 |
| | Fuel Oil #2 | 35,350,121 | 35,118,169 | 35.4 |
| | Unknown | 29,231,359 | 28,999,406 | 29.2 |
| Multifamily | Natural Gas | 26,348,942 | 26,114,495 | 26.3 |
| | Propane | 31,298,029 | 31,063,582 | 31.3 |
| | Fuel Oil #2 | 35,350,121 | 35,115,675 | 35.4 |
| | Unknown | 29,231,359 | 28,996,912 | 29.2 |
| Unknown | Natural Gas | 26,348,942 | 26,116,740 | 26.3 |
| | Propane | 31,298,029 | 31,065,827 | 31.3 |
| | Fuel Oil #2 | 35,350,121 | 35,117,919 | 35.4 |
| | Unknown | 29,231,359 | 28,999,156 | 29.2 |

³⁵³ NEEP Cold Climate Air Source Heat Pump Specification (Version 4.0). https://neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final_1.pdf, accessed August 15, 2024.

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HPheat}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 112)³⁵⁴

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 112)³⁵⁵

Table 112. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |

³⁵⁴ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the "unknown" building type category by weighting according to the population of each building type in the respective studies.

³⁵⁵ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{ave, fuel}$) |
|--------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Wood | 8% | 1% | 7% | 0.53 |

$$CO2e_{HPheat} = \text{Annual } CO2e \text{ emissions [g] due to heat pump heating operation} = (E_{hl} / (HSPF2/0.90) \times 3.412) \times Cl_{elec} / (1 - TDLelec)$$

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh]. Use actual or assume 8.5 if unknown.

0.90 = Conversion factor to convert HSPF2 to HSPF³⁵⁶

3.412 = Btu per Watt-hour. Used to convert HSPF [Btu/(Watt hour)] to COP [dimensionless]. COP = HSPF2/3.412.

$$E_{hl} = \text{Heating load served by the heat pump [MJ]} = (HCAP_{47F} \times EFLH_{heat}) \times 0.00106$$

HCAP_{47F} = Rated heating output capacity of heat pump at 47 °F in Btu's per hour [Btu/h]

EFLH_{heat} = Equivalent full load heating hours = 1,909 hours.³⁵⁷

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{HPcool} = \text{CO2e emissions impact [g] due to added cooling load} = (\Delta E_{cool} \times Cl_{elec}) / (1 - TDLelec)$$

$$\Delta E_{cool} = \text{Cooling energy impacts [MJ]} = -((1 - \%Cool) \times (CCAP \times EFLH_{cool}) / SEER2) \times 0.0036$$

%Cool = Presence of central cooling.³⁵⁸

| Central Cooling? | %Cool |
|--------------------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 7% |
| Unknown, Multifamily | 6% |
| Unknown, Building Type Unknown | 6.9% |

³⁵⁶ Illinois TRM v12.0. "Consortium for Energy Efficiency (CEE), Testing, Testing, M1, 2, 3, Transitioning to New Federal Minimum Standards, CEE Summer Program Meeting, August, 2022."

³⁵⁷ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source "EFLH analysis 2024-08-21" workbook.

³⁵⁸ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

CCAP = Rated cooling output capacity of heat pump in Btu's per hour [Btu/h]

SEER2 = Seasonal Energy Efficiency Rating² (SEER2) for heat pump (cooling efficiency) [Btu/Wh] = 15.

EFLH_{cool} = Equivalent full load cooling hours = 240 hours.³⁵⁹

0.0036 = MJ per Watt-hour.

Common Inputs

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 16 years.³⁶⁰

MEASURE COST

The assumed full retrofit cost of ductless air source heat pumps is below³⁶¹:

| Single-Head | | Multi-Head | |
|------------------|---------------|------------------|---------------|
| Capacity (Btu/h) | Retrofit Cost | Capacity (Btu/h) | Retrofit Cost |
| 6,000 | \$2,759.80 | 18,000 | \$3,494.93 |
| 9,000 | \$2,763.71 | 24,000 | \$3,991.69 |
| 12,000 | \$2,761.05 | 30,000 | \$3,754.15 |
| 15,000 | \$2,894.48 | 36,000 | \$4,342.63 |
| 18,000 | \$3,132.36 | 42,000 | \$5,036.26 |
| 24,000 | \$3,426.49 | 48,000 | \$5,481.42 |
| 40,000 | \$3,981.00 | | |
| 56,500 | \$4,631.10 | | |

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

³⁵⁹ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). "Residential EFLH Cooling is calculated in an analysis of heat pump metered data. The partial load of each heat pump is summed up through the heating season, and taken as an average across all units metered. This analysis can be found on the EFLH Calculator tab in the EVT_CCHP MOP and Retrofit_2018_.xlsx."

³⁶⁰ Illinois TRM v12.0. "Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse 'ComEd Effective Useful Life Research Report', May 2018."

³⁶¹ Vermont 2023 Act 56 Tier III TRM. "Cost analysis of Vermont installed Cold Climate Heat Pumps through Efficiency Vermont's program. Distributor reported costs analyzed in Upstream EVT CCHP Program Data_Cost Analysis.xlsx."

- Rated heating capacity at 47 °F of heat pump (HCAP_{47F}).
- Rated cooling capacity of heat pump (CCAP).

For greater accuracy, the following variables could also be collected:

- Backup heating fuel
- Existing central A/C presence
- Building type (Single Family or Multifamily)

ENERGY CODES AND STANDARDS

NEEP Cold Climate Air Source Heat Pump Specification, Version 4.0.

3.4.7 AIR SOURCE HEAT PUMP – DUCTLESS, PARTIAL DISPLACEMENT

CHS Measure ID: RE_HVAC_HPXP

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of ductless air source heat pumps in residential buildings.

This characterization supports Retrofits in which a heat pump partially displaces a fossil fuel furnace or boiler. The heat pump is assumed to provide heating down to a switchover temperature of 33 °F. Below this temperature, heating is provided by the fossil fuel system.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing central A/C presence and determine cooling impacts on a per site basis. If the home is confirmed to have an existing central A/C system, the algorithm assumes no cooling impacts. If there is no existing central A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing central A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont homes with existing central cooling systems.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is a ductless air source heat pump providing heating at 33 °F and above.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed system is a split system, ductless air source heat pump meeting ENERGY STAR efficiency standards for heat pump split systems (SEER2 \geq 15.2, EER2 \geq 11.7, HSPF2 \geq 7.8)³⁶²
- Heat pump is installed to supplement a fossil fuel system.
- Heat pump cooling capacity is < 65,000 Btu/h

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 113 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Heat pump meets ENERGY STAR minimum efficiency standards for split system heat pumps
- Existing central A/C presence is unknown

Table 113. Example Residential ASHP-Ductless-Partial Displacement CO₂e Reductions

| Building Type | Baseline Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/tonR], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/tonR], Total | Lifetime Credits per Ton _R |
|---------------|-----------------------|---|--|---------------------------------------|
| Single Family | Natural Gas | 8,862,053 | 8,633,152 | 8.9 |
| | Propane | 10,544,742 | 10,315,842 | 10.5 |
| | Fuel Oil #2 | 11,922,454 | 11,693,553 | 11.9 |
| | Unknown | 9,842,074 | 9,613,174 | 9.8 |
| Multifamily | Natural Gas | 8,862,053 | 8,630,691 | 8.9 |
| | Propane | 10,544,742 | 10,313,380 | 10.5 |
| | Fuel Oil #2 | 11,922,454 | 11,691,092 | 11.9 |
| | Unknown | 9,842,074 | 9,610,712 | 9.8 |
| Unknown | Natural Gas | 8,862,053 | 8,632,906 | 8.9 |
| | Propane | 10,544,742 | 10,315,596 | 10.5 |
| | Fuel Oil #2 | 11,922,454 | 11,693,307 | 11.9 |
| | Unknown | 9,842,074 | 9,612,928 | 9.8 |

³⁶² ENERGY STAR Program Requirements: Product Specification for Central Air Conditioner and Heat Pump Equipment: Eligibility Criteria Version 6.1 (Rev. January 2022). <https://www.energystar.gov/sites/default/files/2024-08/ENERGY%20STAR%20Version%206.1%20CACHP%20Final%20Specification%20and%20Partner%20Commitments%20Rev.%20January%202022.pdf>, accessed August 15, 2024.

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HPheat}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 114)³⁶³

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 114)³⁶⁴

Table 114. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |

³⁶³ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the "unknown" building type category by weighting according to the population of each building type in the respective studies.

³⁶⁴ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{ave, fuel}$) |
|--------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Wood | 8% | 1% | 7% | 0.53 |

$$CO2e_{HPheat} = \text{Annual } CO2e \text{ emissions [g] due to heat pump heating operation} = (E_{hl} / (HSPF2/0.90) \times 3.412) \times Cl_{elec} / (1 - TD_{elec})$$

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh]. Use actual or assume 7.8 if unknown.

0.90 = Conversion factor to convert HSPF2 to HSPF³⁶⁵ 3.412 = Btu per Watt-hour. Used to convert HSPF [Btu/(Watt hour)] to COP [dimensionless]. COP = HSPF2/3.412.

$$E_{hl} = \text{Heating load served by the heat pump [MJ]} = (HF \times HCAP_{47F} \times EFLH_{heat}) \times 0.00106$$

HF = Heatload Factor, reduces EFLH to account for partial displacement. = 34%.³⁶⁶

HCAP_{47F} = Rated heating output capacity of heat pump at 47 °F in Btu's per hour [Btu/h]

EFLH_{heat} = Equivalent full load heating hours = 1,909 hours.³⁶⁷

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta CO2e_{HPcool} = \text{CO2e emissions impact [g] due to added cooling load} = (\Delta E_{cool} \times Cl_{elec}) / (1 - TD_{elec})$$

$$\Delta E_{cool} = \text{Cooling energy impacts [MJ]} = -((1 - \%Cool) \times (CCAP \times EFLH_{cool}) / SEER2) \times 0.0036$$

%Cool = Presence of central cooling.³⁶⁸

| Central Cooling? | %Cool |
|--------------------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 7% |
| Unknown, Multifamily | 6% |
| Unknown, Building Type Unknown | 6.9% |

³⁶⁵ Illinois TRM v12.0. "Consortium for Energy Efficiency (CEE), Testing, Testing, M1, 2, 3, Transitioning to New Federal Minimum Standards, CEE Summer Program Meeting, August, 2022."

³⁶⁶ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Based on the ratio of EFLH for a partial displacement heat pump providing heat and outdoor temperatures of 35 °F and above to EFLH for a full displacement heat pump. Source: "EFLH analysis 2024-08-21" workbook.

³⁶⁷ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source "EFLH analysis 2024-08-21" workbook.

³⁶⁸ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

CCAP = Rated cooling output capacity of heat pump in Btu's per hour [Btu/h]

SEER2 = Seasonal Energy Efficiency Rating² (SEER2) for heat pump (cooling efficiency) [Btu/Wh] = 15.2.

EFLH_{cool} = Equivalent full load cooling hours = 240 hours.³⁶⁹

0.0036 = MJ per Watt-hour.

Common Inputs

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 16 years.³⁷⁰

MEASURE COST

The assumed full retrofit cost of ductless air source heat pumps is below³⁷¹:

| Single-Head | | Multi-Head | |
|------------------|---------------|------------------|---------------|
| Capacity (Btu/h) | Retrofit Cost | Capacity (Btu/h) | Retrofit Cost |
| 6,000 | \$2,759.80 | 18,000 | \$3,494.93 |
| 9,000 | \$2,763.71 | 24,000 | \$3,991.69 |
| 12,000 | \$2,761.05 | 30,000 | \$3,754.15 |
| 15,000 | \$2,894.48 | 36,000 | \$4,342.63 |
| 18,000 | \$3,132.36 | 42,000 | \$5,036.26 |
| 24,000 | \$3,426.49 | 48,000 | \$5,481.42 |
| 40,000 | \$3,981.00 | | |
| 56,500 | \$4,631.10 | | |

³⁶⁹ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). "Residential EFLH Cooling is calculated in an analysis of heat pump metered data. The partial load of each heat pump is summed up through the heating season, and taken as an average across all units metered. This analysis can be found on the EFLH Calculator tab in the EVT_CCHP MOP and Retrofit_2018_.xlsx."

³⁷⁰ Illinois TRM v12.0. "Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse 'ComEd Effective Useful Life Research Report', May 2018."

³⁷¹ Vermont 2023 Act 56 Tier III TRM. "Cost analysis of Vermont installed Cold Climate Heat Pumps through Efficiency Vermont's program. Distributor reported costs analyzed in Upstream EVT CCHP Program Data_Cost Analysis.xlsx.."

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity at 47 °F of heat pump (HCAP_{47F}).
- Rated cooling capacity of heat pump (CCAP).

For greater accuracy, the following variables could also be collected:

- Backup heating fuel
- Existing central A/C presence
- Building type (Single Family or Multifamily)

ENERGY CODES AND STANDARDS

ENERGY STAR Product Specification for Central Air Conditioner and Heat Pump Equipment, Version 6.1.

3.4.8 AIR-TO-WATER HEAT PUMPS

CHS Measure ID: RE_HVAC_AWHP

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of an air-to-water heat pump in residential hydronic heating systems, displacing a fossil fuel boiler and serving as the primary heating source. The heat pump is assumed to operate down to an outdoor temperature of -5 °F to +5 °F, at which point the auxiliary heating system assumes the full heating load.

Although air-to-water heat pumps can also produce chilled water for hydronic cooling systems, this feature is not common in residential applications, so this characterization does not include cooling impacts. This characterization also does not include the use of air-to-water heat pumps for domestic hot water heating.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is an air-to-water heat pump serving as the primary heating source above -5 °F to +5 °F.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed system is an air to water heat pump (AWHP)
- Heat pump capacity of ≤ 72,000 Btu/h
- AWHP must be capable of generating 110 °F supply water at an outdoor temperature of 5 °F with a COP of 1.7 or greater.
- Switchover temperature of 5 °F or lower

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 115 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- AWHP COP_{heat} = 2.83

Table 115. Example Residential ASHP-Ducted-Full Displacement CO_{2e} Reductions

| Building Type | Baseline heating fuel | Lifetime CO _{2e} Reductions per Ton _R [g CO _{2e} /ton _R], Thermal Sector | Lifetime CO _{2e} Reductions per Ton _R [g CO _{2e} /ton _R], Total | Lifetime Credits per Ton _R |
|---------------|-----------------------|---|--|---------------------------------------|
| Single Family | Natural Gas | 26,420,711 | 26,420,711 | 26.4 |
| | Propane | 31,369,799 | 31,369,799 | 31.4 |
| | Fuel Oil #2 | 35,421,891 | 35,421,891 | 35.4 |
| | Unknown | 29,303,128 | 29,303,128 | 29.3 |
| Multifamily | Natural Gas | 26,420,711 | 26,420,711 | 26.4 |
| | Propane | 31,369,799 | 31,369,799 | 31.4 |
| | Fuel Oil #2 | 35,421,891 | 35,421,891 | 35.4 |
| | Unknown | 29,303,128 | 29,303,128 | 29.3 |
| Unknown | Natural Gas | 26,420,711 | 26,420,711 | 26.4 |
| | Propane | 31,369,799 | 31,369,799 | 31.4 |
| | Fuel Oil #2 | 35,421,891 | 35,421,891 | 35.4 |
| | Unknown | 29,303,128 | 29,303,128 | 29.3 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO_{2e} Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{direct}} = \text{Annual CO}_2\text{e reduction [g]} \text{ due to equipment replacement} = \text{CO}_2\text{e}_{\text{base}} - \text{CO}_2\text{e}_{\text{HPheat}}$$

$$\text{CO}_2\text{e}_{\text{base}} = \text{Annual CO}_2\text{e emissions [g]} \text{ from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: CO2e}_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline heating fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 116)³⁷²

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 116)³⁷³

Table 116. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |
| Wood | 8% | 1% | 7% | 0.53 |

$$\text{CO2e}_{\text{HPheat}} = \text{Annual CO2e emissions [g] due to heat pump heating operation} = (E_{\text{hl}} / \text{COP}_{\text{hp}}) \times CI_{\text{elec}} / (1 - \text{TDL}_{\text{elec}})$$

COP_{hp} = Coefficient of Performance (COP) rating for heat pump (heating efficiency) [dimensionless]. Use average COP over operating conditions or refer to Table 117 if unknown.

Table 117. Default AWHP Heating Efficiency

| Rated Heating Capacity [tons _R] | COP_{hp} ³⁷⁴ |
|---|---|
| 2.0 | 2.75 |
| 2.5 | 2.76 |

³⁷² Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the “unknown” building type category by weighting according to the population of each building type in the respective studies.

³⁷³ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

³⁷⁴ Vermont 2023 Act 56 Tier III TRM. “The values in the [...] table are a result of weighted averages of available equipment from local distributors binned across Burlington, VT weather data down to an outdoor air temperature of 0°F, averaged across 100°F, 110°F, and 120°F supply water temperatures.”

| Rated Heating Capacity [tons _R] | COP _{hp} ³⁷⁴ |
|--|----------------------------------|
| 3.0 | 2.78 |
| 3.5 | 2.90 |
| 4.0 | 3.03 |
| 4.5 | 2.87 |
| 5.0 | 2.71 |
| 5.5 | 2.80 |
| 6.0 | 2.89 |
| Overall Average | 2.83 |

E_{hl} = Heating load served by the heat pump [MJ] = (HCAP_{47F} × EFLH_{heat}) × 0.00106

HCAP_{47F} = Rated heating output capacity of heat pump at 47 °F in Btu’s per hour [Btu/h]

EFLH_{heat} = Equivalent full load heating hours = 1,909 hours.³⁷⁵

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts: None

Common Inputs

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI’ = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be comparable to an air-to-air heat pump: 16 years.³⁷⁶

MEASURE COST

The assumed measure costs of air-to-water heat pumps are below. These figures include the cost of the AWHP plus additional low temperature emitters, estimated to be \$1,336.³⁷⁷ Low temperature emitters are typically needed with an AWHP installation to allow the AWHP to meet the design load of the building. Existing emitters, often cast iron or older baseboard emitters, were designed for the high supply water temperatures delivered by fossil fuel boilers and do not function well with the lower supply water temperatures produced by AWHPs.

³⁷⁵ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source “EFLH analysis 2024-08-21” workbook.

³⁷⁶ Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.”

³⁷⁷ Vermont 2023 Act 56 Tier III TRM. ““Optimizing Hydronic System Performance in Residential Applications”, NREL, October 2013 (page 8). The cost of low temperature hydronic emitters represents a straight average of the three efficiency scenarios incremental costs’ that were modeled in the report.”

| Rated Heating Capacity [tons _R] | Retrofit Cost ³⁷⁸ |
|---|------------------------------|
| 2 | \$6,404 |
| 3 | \$8,248 |
| 4 | \$10,199 |

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity of heat pump (HCAP).

For greater accuracy, the following variables could also be collected:

- Building type (Single Family or Multifamily)
- Backup heating fuel
- Existing A/C presence

ENERGY CODES AND STANDARDS

N/A

³⁷⁸ Vermont 2023 Act 56 Tier III TRM. “The installation cost is sourced from estimates of two local manufacturers who compared the installation of air to water heat pumps to that of; (1) multi-head mini-split heat pumps, and (2) low temperature condensing boilers. As a result, the estimated installation cost for these two measures was sourced from NEEP Incremental Cost Studies (\$893 for a boiler and \$1,736 for a multi-head mini-split heat pump) and averaged accordingly.”

3.4.9 ERV/HRV

CHS Measure ID: RE_HVAC_ENRV

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family, Multifamily

Decarbonization Pathways: Thermal Efficiency

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Electricity, Wood

Decision/Action Type: MOP

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure relates to the installation of an Energy Recovery Ventilator (ERV) or Heat Recovery Ventilator (HRV) in single family and multifamily homes. Both equipment types provide fresh air ventilation while recovering thermal energy from stale exhaust air and using it to precondition the incoming fresh outdoor air, thereby reducing the heating and cooling loads. The two equipment types differ in that ERVs recover both sensible and latent heat energy, whereas HRVs recover only sensible heat energy. The capability to recover latent energy means that ERVs help to dehumidify the home during the summer, and maintain indoor humidity levels in the winter.

In addition to heating emissions reductions, this characterization includes cooling and fan energy-related reductions.

Baseline Conditions

The baseline condition is a standard HRV or ERV having a sensible heat recovery effectiveness (SRE) of less than 70%, where SRE is defined as the net sensible energy recovered by the supply airstream as adjusted by electric consumption, case heat loss or heat gain, air leakage, airflow mass imbalance between the two airstreams and the energy used for defrost (when running the Very Low Temperature Test), as a percent of the potential sensible energy that could be recovered plus the exhaust fan energy. This value is used to predict and compare Heating Season Performance of the HRV/ERV unit.

Proposed Conditions

The proposed condition is a high efficiency HRV or ERV having an SRE of 70% or greater. There are two categories of high efficiency equipment, based on the SRE:³⁷⁹

| Efficiency Level | HRV | ERV |
|------------------|------------------|------------------|
| Tier 1 | SRE 70% or above | SRE 70% or above |
| Tier 2 | SRE 80% or above | SRE 80% or above |

³⁷⁹ Baseline and proposed conditions align with the 2023 Efficiency Vermont TRM definitions for ERV/HRV.

ELIGIBILITY CRITERIA

The qualifying equipment must be listed in the Home Ventilation Institute's HVI-Certified Ratings Listings for the make and model of the installed system. The HVI-Certified Ratings Listing must include the following:

- Maximum flow rate in cubic feet per minute (CFM)
- Adjusted Sensible Recovery Efficiency (ASRE)
- Adjusted Total Recovery Efficiency (ATRE)

ASRE is similar to SRE but excludes fan or blower energy.³⁸⁰

ATRE is similar to ASRE except includes total energy (sensible plus latent) recovery. ATRE is intended for modeling cooling season energy recovery performance.

DECARBONIZATION SUMMARY

Table 118 provides estimated lifecycle decarbonization ranges over the effective useful life of the measure. These examples are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Central A/C presence is unknown/not collected
- Building type is unknown/not collected
- Heating efficiencies per Table 119.
- Default HRV/ERV size (in CFM) for unknown building type per Table 123.
- Existing home

³⁸⁰ "New Metric Available for HRV and ERV Performance". Home Ventilating Institute, <https://www.hvi.org/resources/publications/builder-guide>.

Table 118. Example ERV and HRV CO₂e Reductions

| Unit Type | Proposed Efficiency Level | Heating Fuel | Lifetime CO ₂ e Reductions, Thermal [g] | Lifetime CO ₂ e Reductions, Total [g] | Lifetime Credits |
|-----------|---------------------------|--------------|--|--|------------------|
| ERV | Tier 1 | Oil | 1,207,962 | 1,274,420 | 1.2 |
| | | Propane | 1,080,831 | 1,147,290 | 1.1 |
| | | Natural Gas | 925,504 | 991,963 | 0.9 |
| | | Electric | 112,223 | 178,681 | 0.1 |
| | | Wood | 865,998 | 932,457 | 0.9 |
| | | Unknown | 987,681 | 1,054,140 | 1.0 |
| | Tier 2 | Oil | 2,030,969 | 2,303,419 | 2.0 |
| | | Propane | 1,817,222 | 2,089,672 | 1.8 |
| | | Natural Gas | 1,556,067 | 1,828,518 | 1.6 |
| | | Electric | 188,682 | 461,133 | 0.2 |
| | | Wood | 1,456,019 | 1,728,470 | 1.5 |
| | | Unknown | 1,660,607 | 1,933,057 | 1.7 |
| HRV | Tier 1 | Oil | 1,088,493 | 1,135,711 | 1.1 |
| | | Propane | 973,936 | 1,021,153 | 1.0 |
| | | Natural Gas | 833,971 | 881,188 | 0.8 |
| | | Electric | 101,124 | 148,342 | 0.1 |
| | | Wood | 780,350 | 827,568 | 0.8 |
| | | Unknown | 889,998 | 937,216 | 0.9 |
| | Tier 2 | Oil | 2,070,792 | 2,264,055 | 2.1 |
| | | Propane | 1,852,853 | 2,046,117 | 1.9 |
| | | Natural Gas | 1,586,578 | 1,779,842 | 1.6 |
| | | Electric | 192,382 | 385,645 | 0.2 |
| | | Wood | 1,484,569 | 1,677,832 | 1.5 |
| | | Unknown | 1,693,168 | 1,886,431 | 1.7 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$\Delta\text{CO}_2\text{e}_{\text{thermal}}$ = Total annual carbon dioxide equivalent emissions reductions in grams [g] = $\Delta\text{CO}_2\text{e}_{\text{heat}}$

Annual Clean Heat Credits = $\Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$

CreditValue = 1 credit/tonneCO₂e

1,000,000 = Grams per metric ton

$\Delta\text{CO}_2\text{e}_{\text{heat}}$ = CO₂e emissions reductions from reducing heating energy

If heating fuel is known:

$$\text{Oil: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: } \Delta\text{CO}_2\text{e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural gas: } \Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,NG}} \times \text{Cl}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

$$\text{Electricity: } \Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,elec}} \times \text{Cl}_{\text{NG}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\text{Wood: } \Delta\text{CO2e}_{\text{heat}} = (\Delta E_{\text{hl}} / \eta_{\text{ave,wood}}) \times (\text{Cl}_{\text{wood}} + \text{Cl}'_{\text{wood}})$$

If heating fuel is unknown:

$$\Delta\text{CO2e}_{\text{heat}} = (\% \text{Oil} \times \Delta E_{\text{hl}} / \eta_{\text{ave,oil}} \times (\text{Cl}_{\text{oil}} + \text{Cl}'_{\text{oil}})) + (\% \text{LP} \times \Delta E_{\text{hl}} / \eta_{\text{ave,LP}} \times (\text{Cl}_{\text{LP}} + \text{Cl}'_{\text{LP}})) + (\% \text{NG} \times \Delta E_{\text{hl}} / \eta_{\text{ave,NG}} \times \text{Cl}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}}) + (\% \text{Elec} \times \Delta E_{\text{hl}} / \eta_{\text{ave,elec}} \times \text{Cl}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}}) + (\% \text{Wood} \times \Delta E_{\text{hl}} / \eta_{\text{ave,wood}} \times (\text{Cl}_{\text{wood}} + \text{Cl}'_{\text{wood}}))$$

%Oil, etc. = Relative proportion of fuel in Vermont's primary heating fuel mix (see Table 119)³⁸¹

Table 119. Vermont Primary Heating Fuel Mix and Average Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|-------------------|---------------|--|
| | Single Family %Fuel | Multifamily %Fuel | Unknown %Fuel | |
| Oil | 45% | 5% | 41% | 0.84 |
| Propane (LP) | 17% | 5% | 16% | 0.83 |
| Natural Gas (NG) | 23% | 66% | 27% | 0.85 |
| Electricity | 6% | 23% | 8% | 2.52 |
| Wood | 8% | 1% | 7% | 0.53 |

$$\Delta E_{\text{hl}} = \text{Reduction in heating load [MJ]} = (1.08 \times \text{CFM}_{\text{ave}} \times \text{HDH} \times (\text{ASRE}_{\text{EE}} - \text{ASRE}_{\text{Base}})) \times 0.00106$$

$$1.08 = \text{Specific heat of air} \times \text{density of air} \times 60 \text{ min/hr [BTU/(CFM}^\circ\text{F hr)]}$$

$$\text{HDH} = \text{Heating Degree Hours [}^\circ\text{F hr]} = 129,936 \text{ }^{382}$$

$\text{ASRE}_{\text{Base}}$ = Adjusted Sensible Recovery Efficiency of the baseline ERV or HRV; see Table 124.³⁸³

ASRE_{EE} = Adjusted Sensible Recovery Efficiency of the efficient ERV or HRV; see Table 124.

Non-Thermal Sector CO2e Impacts:

$$\Delta\text{CO2e}_{\text{cool}} = \text{CO2e emissions reductions [g]} \text{ from reducing cooling energy} = (\Delta E_{\text{cl}} / \eta_{\text{cool}} \times \text{Cl}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cl}} = \text{Reduction in cooling load [MJ]} = (\% \text{Cool} \times 4.5 \times \text{CFM}_{\text{ave}} \times \Delta H \times (\text{ATRE}_{\text{EE}} - \text{ATRE}_{\text{Base}})) \times 0.00106$$

³⁸¹ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the "unknown" building type category by weighting according to the population of each building type in the respective studies.

³⁸² 2023 Efficiency Vermont TRM, ERV/HRV. Assumes 58°F base temperature.

³⁸³ *Ibid.*

%Cool = Presence of central cooling³⁸⁴

| Central Cooling? | %Cool | |
|--------------------------------|---------------|------------------|
| | Existing Home | New Construction |
| Yes | 100% | |
| No | 0% | |
| Unknown, Single Family | 7% | 41% |
| Unknown, Multifamily | 6% | 41% |
| Unknown, Unknown Building Type | 6.9% | 41% |

4.5 = Density of air x 60 min/hr [(lb min)/(ft³ hr)]

ΔH = Product of the difference between outdoor air and return air enthalpies at each outdoor air enthalpy bin above 70 °F and the number of hours at each bin [(Btu/lb) hr] = 6,360 ³⁸⁵

ATRE_{Base} = Adjusted Total Recovery Efficiency of the baseline ERV or HRV; see Table 124.

ATRE_{EE} = Adjusted Total Recovery Efficiency of the efficient ERV or HRV; see Table 124.

η_{cool} = Cooling system efficiency = 5.72.³⁸⁶

$\Delta CO2e_{fan}$ = CO2e emissions reductions [g] from reducing fan energy = $(\Delta E_{fan} \times CI_{elec}) / (1 - TDL_{elec})$

ΔE_{fan} = Reduction in ERV/HRV fan energy = $((Watts_{Ave,Base} - Watts_{Ave,EE}) \times 8760) \times 0.0036$

Watts_{Ave,Base} = Average operating wattage of baseline HRV/ERV; see Table 120 if size is known or refer to Table 121.

Watts_{Ave,EE} = Average operating wattage of high efficiency ERV/HRV; see Table 120 if size is known or refer to Table 121.

Table 120. ERV/HRV Average Wattages by Unit Size

| Unit Type | Size [CFM] | Baseline | Tier 1 | Tier 2 |
|-----------|------------|---------------------------|-------------------------|-------------------------|
| | | Watts _{Ave,Base} | Watts _{Ave,EE} | Watts _{Ave,EE} |
| ERV | 30 - 79 | 42.8 | 37.6 | 21 |
| | 80 - 129 | 48.5 | 42.5 | 23.8 |
| | 130 - 179 | 58.2 | 51 | 28.6 |
| | 180 - 229 | 68.7 | 60.2 | 33.8 |

³⁸⁴ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Because the sample size of multifamily new construction buildings was very small, single family new construction values were used as a proxy. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

³⁸⁵ Calculated with TMY3 data for Burlington, VT. Assumes return air enthalpy of 25.3 Btu/lb based on 70 °F at 50% relative humidity.

³⁸⁶ NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, statewide mean value, Table 83.

| Unit Type | Size [CFM] | Baseline | Tier 1 | Tier 2 |
|-----------|------------|---------------------------|-------------------------|-------------------------|
| | | Watts _{Ave,Base} | Watts _{Ave,EE} | Watts _{Ave,EE} |
| | 230+ | 93 | 81.5 | 45.7 |
| HRV | 30 - 79 | 43.4 | 39.6 | 27.8 |
| | 80 - 129 | 49.1 | 44.8 | 31.5 |
| | 130 - 179 | 58.9 | 53.7 | 37.8 |
| | 180 - 229 | 69.5 | 63.4 | 44.6 |
| | 230+ | 94.1 | 85.8 | 60.3 |

Table 121. ERV/HRV Default Wattages by Building type

| Unit Type | Building Type | Average Size | Baseline | Tier 1 | Tier 2 |
|-----------|---------------|--------------------|---------------------------|-------------------------|-------------------------|
| | | CFM _{ave} | Watts _{Ave,Base} | Watts _{Ave,EE} | Watts _{Ave,EE} |
| ERV | Single Family | 114 | 48.5 | 42.5 | 23.8 |
| | Multifamily | 64 | 42.8 | 37.6 | 21.0 |
| | Unknown | 99 | 48.5 | 42.5 | 23.8 |
| HRV | Single Family | 114 | 49.1 | 44.8 | 31.5 |
| | Multifamily | 64 | 43.4 | 39.6 | 27.8 |
| | Unknown | 99 | 49.1 | 44.8 | 31.5 |

8760 = hours per year

0.0036 = MJ per Watt-hour.

Common Inputs

CFM_{ave} = Average volumetric flow of supply air [CFM] to the ERV. Select based on Table 122 if size is known, or use defaults from Table 123.³⁸⁷

Table 122. Residential HRV/ERV: Assumed Average Operating Supply Airflow by Unit Size

| Size [CFM] | Assumed Average Supply Airflow (CFM _{ave}) |
|------------|--|
| 30 - 79 | 53 |
| 80 - 129 | 60 |
| 130 - 179 | 72 |
| 180 - 229 | 85 |
| 230+ | 115 |

³⁸⁷ Table 3: 2023 Efficiency Vermont TRM, ERV/HRV. Table 4: Average Size [CFM] from Illinois TRM V12.0 Volume 3, page 222; "Table of ERV Default Values is based on all available ERV Certified Data from file 'HVIProd_ER.xlsx' published by Home Ventilating Institute (<https://www.hvi.org/hvi-certified-products-directory/section-iii-hrv-erv-directory-listing/>). This table lists certified values of 387 models of ERVs. The default values above assume that Single-family residences will install ERVs with Heating CFM > 75 and Multi-family residences will install ERVs with Heating CFM <= 75 cfm."

Table 123. Residential ERV/HRV: Default Supply Air Volumetric Flow (CFM) by Building type

| Building Type | Average Size [CFM] | Assumed Average Supply Airflow (CFM _{ave}) |
|---------------|--------------------|--|
| Single Family | 114 | 60 |
| Multifamily | 64 | 53 |
| Unknown | 99 | 60 |

Table 124. ERV/HRV Adjusted Sensible and Total Recovery Efficiency (ASRE and ATRE, respectively)

| Unit Type | Efficiency Category | Average ASRE | Average ATRE |
|-----------|---------------------|--------------|--------------|
| ERV | Baseline | 70.0% | 50.2% |
| | Tier 1 SRE 70% + | 79.1% | 57.7% |
| | Tier 2 SRE 80% + | 85.3% | 66.2% |
| HRV | Baseline | 70.8% | N/A |
| | Tier 1 SRE 70% + | 79.0% | N/A |
| | Tier 2 SRE 80% + | 86.4% | N/A |

0.00106 = MJ per BTU.

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life of installed equipment is estimated to be 15 years.³⁸⁸

MEASURE COST

The incremental measure costs for installing Tier 1 or Tier 2 equipment are presented in Table 125.³⁸⁹

Table 125. ERV/HRV Measure Cost

| Efficiency Category | ERV | HRV |
|---------------------|----------|----------|
| Tier 1 | \$141.00 | \$154.00 |
| Tier 2 | \$552.00 | \$345.00 |

³⁸⁸ 2023 Efficiency Vermont TRM, ERV/HRV. "Consistent with Tracker default assumptions."

³⁸⁹ 2023 Efficiency Vermont TRM, ERV/HRV. "Internet-sourced pricing data used to establish incremental costs. See 'HVI_ER_HRV' and 'Cost data' sheets of ERV_HRV_Analysis_2022.xlsx for more details."

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- Heating fuel type
- Heating system type
- Unit type (ERV or HRV)
- Max rated CFM
- ERV/HRV Adjusted Sensible Heat Recovery (ASRE_{EE})
- ERV/HRV Adjusted Total Heat Recovery (ATRE_{EE})

For greater accuracy, the following variables could additionally be collected:

- Central cooling presence
- Building type (single family or multifamily)

ENERGY CODES AND STANDARDS

The 2020 Vermont Residential Building Energy Standards requires that buildings be provided with ventilation that meets the requirements of the International Residential Code or International Mechanical Code, as applicable, or with other approved means of ventilation.³⁹⁰

3.4.10 GROUND SOURCE HEAT PUMP

CHS Measure ID: RE_HVAC_GSHP

Market Sector: Residential

End Use: HVAC

Applicable Building Types: Single Family

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Wood, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure characterizes carbon reductions achieved through the installation of ENERGY STAR-qualified ground source heat pumps in residential buildings, displacing fossil fuel systems. Ground source heat pumps (GSHP), also known as geothermal heat pumps, utilize the ground or groundwater as a thermal energy source to efficiently provide space conditioning. This characterization supports six types of GSHP systems as defined in ENERGY STAR specifications for geothermal heat pump systems:

- Water-to-Air, Closed Loop
- Water-to-Air, Open Loop
- Water-to-Water, Closed Loop
- Water-to-Water, Open Loop
- DGX-to-Air
- DGX-to-Water

“Closed Loop” refers to systems in which the heat transfer fluid (typically a water-based solution) is permanently contained in a closed piping system.

“Open Loop” refers to systems that use pumped groundwater from an aquifer or well as a heat source.

“DGX” stands for “Direct Geoexchange” and refers to systems in which the refrigerant is used as the heat transfer fluid instead of a secondary heat transfer fluid such as water.

This characterization supports two different options for determining cooling impacts:

- Programs can track existing central A/C presence and determine cooling impacts on a per site basis. If the home is confirmed to have an existing central A/C system, the algorithm assumes no cooling impacts. If there is no existing central A/C system, then the heat pump is assumed to add cooling load that did not previously exist.
- If existing central A/C presence is not tracked, increased cooling load is assumed, but here the increased load is derated to account for the percentage of Vermont homes with existing central cooling systems.

GSHP systems can provide domestic water heating through add-on systems called desuperheaters. This characterization does not include desuperheaters.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical heating system consuming a representative mix of oil, natural gas, propane, electricity, and wood. This baseline scenario is intended to represent average per site baseline CO₂e emissions.
2. An oil, natural gas or propane heating system. This baseline scenario allows for site-specific baseline CO₂e emissions.

Proposed Conditions

The proposed condition is an ENERGY STAR-qualified GSHP serving as the primary heating system.

ELIGIBILITY CRITERIA

The following criteria must be met to use this characterization:

- Installed GSHP is ENERGY STAR-qualified and meets ENERGY STAR minimum heating (COP) and cooling (EER) efficiencies:³⁹¹

Table 126. ENERGY STAR GSHP Minimum Heating and Cooling Efficiency

| GSHP Type | EER (Cooling) | COP (Heating) |
|----------------------------|------------------|------------------|
| Water-to-Air | | |
| Closed Loop Water-to-Air | 17.1 | 3.6 |
| Open Loop Water-to-Air | 21.1 | 4.1 |
| Water-to-Water | | |
| Closed Loop Water-to-Water | 16.1 | 3.1 |
| Open Loop Water-to-Water | 20.1 | 3.5 |
| DGX | | |
| DGX-to-Air | 16.0 | 3.6 |
| DGX-to-Water | 15.0 | 3.1 |

This characterization is intended for fossil fuel to electric conversions. Wood and electric heating systems are only considered as a baseline component when the baseline heating fuel is not collected.

DECARBONIZATION SUMMARY

Table 127 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 ton_R = 12,000 Btu/h) for full displacement heat pumps over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

³⁹¹ ENERGY STAR® Program Requirements Product Specification for Geothermal Heat Pumps: Eligibility Criteria Version 3.2. <https://www.energystar.gov/sites/default/files/asset/document/Geothermal%20Heat%20Pumps%20Version%203.2%20Final%20Specification.pdf>, accessed September 2, 2024.

Assumptions:

- GSHP meets ENERGY STAR minimum efficiency standards
- Existing central A/C presence is unknown

Table 127. Example Residential GSHP Lifetime CO₂e Reductions per Ton_R

| GSHP Type | Baseline Heating Fuel | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Thermal Sector | Lifetime CO ₂ e Reductions per Ton _R [g CO ₂ e/ton _R], Total | Lifetime Credits per Ton _R |
|-----------------------------|-----------------------|--|---|---------------------------------------|
| Water-to-Air, Closed Loop | Natural Gas | 43,455,456 | 43,187,568 | 43.5 |
| | Propane | 49,333,522 | 49,065,634 | 49.3 |
| | Fuel Oil #2 | 56,910,599 | 56,642,711 | 56.9 |
| | Unknown | 46,513,663 | 46,245,775 | 46.5 |
| Water-to-Air, Open Loop | Natural Gas | 43,845,830 | 43,628,726 | 43.8 |
| | Propane | 49,723,897 | 49,506,793 | 49.7 |
| | Fuel Oil #2 | 57,300,974 | 57,083,870 | 57.3 |
| | Unknown | 46,904,038 | 46,686,934 | 46.9 |
| Water-to-Water, Closed Loop | Natural Gas | 42,939,154 | 42,654,627 | 42.9 |
| | Propane | 48,817,221 | 48,532,694 | 48.8 |
| | Fuel Oil #2 | 56,394,298 | 56,109,771 | 56.4 |
| | Unknown | 45,997,362 | 45,712,835 | 46.0 |
| Water-to-Water, Open Loop | Natural Gas | 43,363,996 | 43,136,092 | 43.4 |
| | Propane | 49,242,063 | 49,014,158 | 49.2 |
| | Fuel Oil #2 | 56,819,140 | 56,591,235 | 56.8 |
| | Unknown | 46,422,204 | 46,194,299 | 46.4 |
| DGX-to-Air | Natural Gas | 43,455,456 | 43,169,150 | 43.5 |
| | Propane | 49,333,522 | 49,047,217 | 49.3 |
| | Fuel Oil #2 | 56,910,599 | 56,624,294 | 56.9 |
| | Unknown | 46,513,663 | 46,227,358 | 46.5 |
| DGX-to-Water | Natural Gas | 42,939,154 | 42,633,762 | 42.9 |
| | Propane | 48,817,221 | 48,511,828 | 48.8 |
| | Fuel Oil #2 | 56,394,298 | 56,088,905 | 56.4 |
| | Unknown | 45,997,362 | 45,691,969 | 46.0 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO₂e Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

1,000,000 = Grams per metric ton

$$\Delta CO_2e_{\text{direct}} = \text{Annual } CO_2e \text{ reduction [g] due to equipment replacement} = CO_2e_{\text{base}} - CO_2e_{\text{HPheat}}$$

$$CO_2e_{\text{base}} = \text{Annual } CO_2e \text{ emissions [g] from baseline heating system}$$

If baseline fuel is known:

$$\text{Oil: } CO_2e_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,oil}}) \times (CI_{\text{oil}} + CI'_{\text{oil}})$$

$$\text{Propane: } CO_2e_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,LP}}) \times (CI_{\text{LP}} + CI'_{\text{LP}})$$

$$\text{Natural gas: } CO_2e_{\text{base}} = (E_{\text{hl}} / \eta_{\text{ave,NG}} \times CI_{\text{NG}}) / (1 - TDL_{\text{NG}})$$

If baseline heating fuel is unknown:

$$CO_2e_{\text{base}} = ((\% \text{Oil} \times E_{\text{hl}} \times (CI_{\text{oil}} + CI'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{hl}} \times (CI_{\text{LP}} + CI'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{hl}} \times CI_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - TDL_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{hl}} \times CI_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - TDL_{\text{elec}}) + ((\% \text{Wood} \times E_{\text{hl}} \times (CI_{\text{wood}} + CI'_{\text{wood}})) / \eta_{\text{ave,wood}})$$

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 128)³⁹²

$\eta_{\text{ave,fuel}}$ = Average heating efficiency by fuel type [dimensionless] (see Table 128)³⁹³

Table 128. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | Average Existing Heating Efficiency ($\eta_{\text{ave,fuel}}$) |
|------------------|---------------------|--|
| | Single Family %Fuel | |
| Oil | 45% | 0.84 |
| Propane (LP) | 17% | 0.83 |
| Natural Gas (NG) | 23% | 0.85 |
| Electricity | 6% | 2.52 |
| Wood | 8% | 0.53 |

$$CO_2e_{\text{HPheat}} = \text{Annual } CO_2e \text{ emissions [g] due to heat pump heating operation} =$$

$$(E_{\text{hl}} / \text{COP}) \times CI_{\text{elec}} / (1 - TDL_{\text{elec}})$$

COP = Rated heating Coefficient of Performance (COP) for heat pump [dimensionless] under ISO 13256-1 test conditions. Use actual or assume ENERGY STAR minimum standard (see Table 126).

³⁹² Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study and NMR Group, 2020 Vermont Multifamily Residential Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The single family and multifamily results are combined for the “unknown” building type category by weighting according to the population of each building type in the respective studies.

³⁹³ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. Assumes 50%/50% split between wood stoves and gas fireplaces. Gas fireplaces are split between natural gas and propane according to survey results for each fuel. The data organization in the 2020 Vermont Multifamily Residential Baseline Study did not allow for computing multifamily-specific average heating efficiencies.

$$E_{hl} = \text{Heating load served by the heat pump [MJ]} = (\text{HCAP}_{47F} \times \text{EFLH}_{\text{heat}}) \times 0.00106$$

HCAP_{47F} = Rated heating output capacity of heat pump at 47 °F in Btu’s per hour [Btu/h]

$\text{EFLH}_{\text{heat}}$ = Equivalent full load heating hours = 1,909 hours.³⁹⁴

0.00106 = MJ per Btu.

Non-Thermal Sector CO2e Impacts:

$$\Delta\text{CO2e}_{\text{HPcool}} = \text{CO2e emissions impact [g]} \text{ due to added cooling load} = (\Delta E_{\text{cool}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta E_{\text{cool}} = \text{Cooling energy impacts [MJ]} = -((1 - \% \text{Cool}) \times (\text{CCAP} \times \text{EFLH}_{\text{cool}}) / \text{EER}) \times 0.0036$$

$\% \text{Cool}$ = Presence of central cooling.³⁹⁵

| Central Cooling? | %Cool |
|------------------------|-------|
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 7% |

CCAP = Rated cooling output capacity of heat pump in Btu’s per hour [Btu/h]

EER = Energy Efficiency Rating (EER) for heat pump (cooling efficiency) under ISO 13256-1 test conditions [Btu/Wh]. Use actual or assume ENERGY STAR minimum standard (see Table 126).

$\text{EFLH}_{\text{cool}}$ = Equivalent full load cooling hours = 240 hours.³⁹⁶

0.0036 = MJ per Watt-hour.

Common Inputs

CI = Carbon intensity [g CO2e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO2e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

³⁹⁴ Derived from a bin analysis using TMY3 weather data for Burlington, VT. Average of EFLH measured at design temperature of -15 °F, balance points of 60 °F or 65 °F, and switchover temperatures of -5 °F, 0 °F, and 5 °F. Assumes heat pump is sized to the design heating load. Source “EFLH analysis 2024-08-21” workbook.

³⁹⁵ Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 58; NMR Group, 2020 Vermont Multifamily Residential Baseline Study, Table 63; and NMR Group, 2020 Vermont Single Family Residential New Construction Baseline and Code Compliance Study. Unknown building type values were calculated as weighted average of single family existing and multifamily existing values, with weighting factors according to population sizes in Table 2 and Table 3 of the respective studies.

³⁹⁶ Efficiency Vermont 2023 TRM, Ducted Air Source Heat Pump (Market Opportunity). “Residential EFLH Cooling is calculated in an analysis of heat pump metered data. The partial load of each heat pump is summed up through the heating season, and taken as an average across all units metered. This analysis can be found on the EFLH Calculator tab in the EVT_CCHP MOP and Retrofit_2018_.xlsx.”

MEASURE LIFE

The largest cost component of GSHP installations is typically the wellfields or ground loops. If installed properly, the underground piping should not need replacement. While the heat pump itself may need replacement within a more normal lifespan for energy efficiency measures, the cost of the heat pump is usually significantly less than the wellfields or ground loops. Accordingly, this measure is granted a measure life of 25 years, reflecting the long lifespan of the ground piping.³⁹⁷

MEASURE COST

The cost of GSHP installations varies widely with the specific conditions of each site. Accordingly, the actual installed cost (material, labor, and miscellaneous costs) of each GSHP installation should be tracked.

- For retrofits, \$3957 per ton may be assumed for planning purposes.³⁹⁸

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Rated heating capacity of heat pump (HCAP).
- Rated cooling capacity of heat pump (CCAP).
- Type of GSHP installed:
 - Closed Loop Water-to-Air
 - Open Loop Water-to-Air
 - Closed Loop Water-to-Water
 - Open Loop Water-to-Water
 - DGX-to-Air
 - DXG-to-Water
- Existing heating fuel

For greater accuracy, the following variables could also be collected:

- Rated COP of heat pump (COP)
- Rated EER of heat pump (EER)
- Existing central A/C presence

³⁹⁷ Consistent with New York TRM v11 and Illinois TRM v12.0 measure life assumptions.

³⁹⁸ Illinois TRM v12.0. "Based on data provided in 'Results of Home geothermal and air source heat pump rebate incentives documented by IL electric cooperatives'."

ENERGY CODES AND STANDARDS

ENERGY STAR® Program Requirements Product Specification for Geothermal Heat Pumps: Eligibility Criteria
Version 3.2.

3.5 MISCELLANEOUS

3.5.1 EFFICIENT AND ELECTRIC MANUFACTURED HOMES

CHS Measure ID: RE_HOME_MANU

Market Sector: Residential

End Use: HVAC, Domestic Hot Water, Appliances

Applicable Building Types: Single Family

Decarbonization Pathways: Weatherization, Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil

Decision/Action Type: MOP:New Construction

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the construction and installation of an all-electric manufactured home that exceeds Department of Energy (DOE) Zero Energy Ready Home Manufactured Home (ZERH MH) Version 1 criteria.

ZERH MH Version 1 criteria provide minimum mandatory efficiency requirements for envelope, glazing, thermostats and duct insulation, and additional efficiency requirements to achieve a total of at least 18 points through additional envelope, heating, cooling, hot water or lighting and appliance upgrades. See 'DOE ZERH MH V1 National Program Requirements' for more information.

This characterization aligns with the Efficiency Vermont implementation of this measure as outlined in the 2023 Efficiency Vermont TRM which is providing incentives to exceed the DOE minimum points requirement and to achieve at least 30 points, requiring both a higher efficiency envelope and heat pumps for space and water heating.

Baseline Conditions

The baseline is a weighted average of the modelled energy consumption of single and double wide manufactured homes meeting two standards: 1) US Department of Housing and Urban Development (HUD) standard for manufactured homes, and 2) ENERGY STAR Manufactured New Homes National Program Requirements Version (3). The baseline weighting assumes 75% built to HUD standard and 25% to ENERGY STAR Version 3 standard as an estimate of future market share.³⁹⁹

Proposed Conditions

The proposed condition is a simple average of the modelled energy consumption of single and double wide manufactured homes meeting two standards used by two of the leading manufacturers for shipment to Vermont. These specifications achieve 30 and 34.5 additional points on the DOE ZERH MH Version 1 criteria.

³⁹⁹ Note that the latest available data (2020) indicated an ENERGY STAR Version 2 market share of 69% (ENERGY_STAR_Manufactured_Homes_Market_Share_Report.pdf (research-alliance.org)) - however this was likely heavily skewed by the timing of this data where the availability of VHFA loans required ENERGY STAR ratings and further the step up from ENERGY STAR Version 2 to Version 3 is likely to result in a lower market share going forward.

ELIGIBILITY CRITERIA

The manufactured home must be new construction, all-electric, and achieve at least 30 points on the DOE ZERH MH Version 1 criteria.

DECARBONIZATION SUMMARY

Table 129 provides lifecycle CO₂e reductions for single and double wide efficient and electric manufactured homes.

Assumptions:

- Baseline and proposed conditions described above

Table 129. Efficient and Electric Manufactured Home CO₂e Reduction Summary

| Manufactured Home Size | Lifetime CO ₂ e Reductions [g], Thermal Sector | Lifetime CO ₂ e Reductions [g], Total | Lifetime Credits |
|------------------------|---|--|------------------|
| Single | 68,748,013 | 69,260,476 | 68.7 |
| Double | 69,338,414 | 69,838,680 | 69.3 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector Decarbonization Reductions:

$$\Delta\text{CO}_2\text{e}_{\text{thermal}} = \text{Annual thermal sector CO}_2\text{e reductions in grams [g]} = \Delta\text{CO}_2\text{e}_{\text{heat}} + \Delta\text{CO}_2\text{e}_{\text{DHW}} + \Delta\text{CO}_2\text{e}_{\text{other}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO}_2\text{e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO}_2\text{e}$$

$$1,000,000 = \text{Grams per metric ton}$$

$$\Delta\text{CO}_2\text{e}_{\text{heat}} = \text{CO}_2\text{e emissions reductions for space heating} = \Delta\text{CO}_2\text{e}_{\text{heat,base}} + \Delta\text{CO}_2\text{e}_{\text{heat,elec}}$$

$$\Delta\text{CO}_2\text{e}_{\text{heat,base}} = (\Delta E_{\text{heat,LP}} \times (C_{\text{LP}} + C'_{\text{LP}})) + (\Delta E_{\text{heat,oil}} \times (C_{\text{oil}} + C'_{\text{oil}}))$$

$$\Delta\text{CO}_2\text{e}_{\text{heat,elec}} = (\Delta E_{\text{heat,elec}} \times C_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta\text{CO}_2\text{e}_{\text{DHW}} = \text{CO}_2\text{e emissions reductions for domestic hot water} = \Delta\text{CO}_2\text{e}_{\text{DHW,base}} + \Delta\text{CO}_2\text{e}_{\text{DHW,elec}}$$

$$\Delta\text{CO}_2\text{e}_{\text{DHW,base}} = \Delta E_{\text{DHW,LP}} \times (C_{\text{LP}} + C'_{\text{LP}})$$

$$\Delta\text{CO}_2\text{e}_{\text{DHW,elec}} = (\Delta E_{\text{DHW,elec}} \times C_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

$$\Delta\text{CO}_2\text{e}_{\text{other}} = \text{CO}_2\text{e emissions reductions for other end uses (mostly clothes drying)} = (\Delta E_{\text{other}} \times C_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

Non-Thermal Sector Decarbonization Impacts:

$$\Delta\text{CO}_2\text{e}_{\text{cool}} = \text{CO}_2\text{e emissions impacts for space cooling} = (\Delta E_{\text{cool}} \times \text{CI}_{\text{elec}}) / (1 - \text{TDL}_{\text{elec}})$$

Common Inputs

Energy savings in megajoules [MJ] are prescribed for each end use according to the following table. The savings per home are equal to the sum of the four end use categories below.⁴⁰⁰

| End Use | Variable Name | Single Wide – Savings [MJ] | | | Double Wide – Savings [MJ] | | |
|---------------|--------------------------------|----------------------------|----------|----------|----------------------------|----------|---------|
| | | Electric | Propane | Oil | Electric | Propane | Oil |
| Space Heating | $\Delta E_{\text{heat, fuel}}$ | -10,619.6 | 40,725.2 | 10,128.5 | -9,486.7 | 38,193.0 | 9,495.5 |
| Space Cooling | ΔE_{cool} | 1,420.2 | | | 1,386.4 | | |
| Water Heating | $\Delta E_{\text{DHW, fuel}}$ | 239.8 | 12,238.6 | | -1,959.1 | 17,513.9 | |
| Other | ΔE_{Other} | 695.9 | | | 780.1 | | |

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

Each end use is assigned a measure life as follows:

- Space Heating – 16 years (consistent with heat pump measures)
- Space Cooling – 16 years (consistent with heat pump measures)
- Water Heating – 12 years (consistent with heat pump water heater measure)
- Other – 12 years (consistent with ENERGY STAR Dryer measure)

MEASURE COST

The following incremental cost assumptions are based on quotes from manufactured home vendors and other TRM estimates. Shell, HVAC, ERV and electric panel costs were split between the heating and cooling measures based on weighting of savings.

| End Use | Single | Double |
|--------------|---------|---------|
| Heating | \$6,704 | \$7,646 |
| Cooling | \$264 | \$301 |
| Water Heater | \$1,795 | \$1,750 |
| Other | \$233 | \$175 |

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

⁴⁰⁰ Efficiency Vermont 2023 TRM, workbook “AMH2023-Modelling_082823”.

- Manufactured home size (Single or Double)

ENERGY CODES AND STANDARDS

US Department of Housing and Urban Development Manufactured Home Construction and Safety Standards (24 CFR Part 3280)⁴⁰¹

ENERGY STAR Manufactured New Homes National Program Requirements, Version 3⁴⁰²

US Department of Energy Zero Energy Ready Home Manufactured Home (ZERH MH), Version 1⁴⁰³

⁴⁰¹ <https://www.ecfr.gov/current/title-24/subtitle-B/chapter-XX/part-3280>, accessed August 22, 2024.

⁴⁰² <https://www.energystar.gov/sites/default/files/2024-07/ENERGY%20STAR%20Manufactured%20New%20Homes%20Program%20Requirements%2C%20Version%203%20%28Rev.%2002%29.pdf>, accessed August 22, 2024.

⁴⁰³ <https://www.energy.gov/sites/default/files/2022-12/DOE%20ZERH%20MH%20V1%20National%20Program%20Requirements.pdf>, accessed August 22, 2024.

3.5.2 HEAT PUMP POOL WATER HEATER

CHS Measure ID: RE_MISC_HPPW

Market Sector: Residential

End Use: Miscellaneous

Applicable Building Types: Single Family

Decarbonization Pathways: Electrification

Applicable Baseline Fuels: Natural Gas, Propane, Fuel Oil #2, Electricity

Decision/Action Type: Retrofit

Program Delivery Type: Downstream

MEASURE DESCRIPTION

This measure involves the replacement of an existing fossil fuel pool water heater with a heat pump pool water heater providing heat to in-ground, outdoor residential pools. The heat pump pool water heater uses heat pump technology to transfer heat from the air to pool water. Pool heating is used to heat the pool at the beginning of the season and counteract heat losses due to evaporation and convection.

Baseline Conditions

The assumed baseline may be one of the following conditions:

1. A hypothetical conventional pool heater consuming a representative mix of oil, natural gas, propane, and electricity. This scenario is suitable if the baseline heater fuel is not collected.
2. The existing oil, natural gas or propane pool heater. This scenario is suitable if the baseline heater fuel is collected.

Proposed Conditions

The proposed condition is a heat pump pool water heater.

ELIGIBILITY CRITERIA

This measure is only applicable to residential, in-ground outdoor pools and does not apply to spas. The pool heater must have a COP of at least 4.0.

This characterization is intended for fuel switching scenarios. Electric heaters are only considered as a baseline component when the baseline heater fuel is not collected.

DECARBONIZATION SUMMARY

Table 130 provides estimated lifecycle decarbonization ranges for example baseline and proposed conditions over the effective useful life of the measure. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Assumptions:

- Average baseline pool heater efficiencies in Table 131
- Heat pump pool water heater COP = 4.79
- 36ft by 18ft pool kept at 82 °F from June 1 through September 30
- Pool cover use is unknown

Table 130. Example Residential Heat Pump Pool Water Heater CO2e Reductions

| Baseline Fuel | Lifetime CO2e reductions [g], Thermal Sector | Lifetime CO2e reductions [g], Total | Lifetime Credits |
|---------------|--|-------------------------------------|------------------|
| Oil | 50,105,786 | 50,105,786 | 50.1 |
| Propane | 43,632,750 | 43,632,750 | 43.6 |
| Natural Gas | 37,483,152 | 37,483,152 | 37.5 |
| Unknown | 29,992,952 | 29,992,952 | 30.0 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

Thermal Sector CO2e Reductions:

$$\Delta\text{CO2e}_{\text{thermal}} = \text{Annual thermal sector CO2e reductions in grams [g]} = \Delta\text{CO2e}_{\text{direct}}$$

$$\text{Annual Clean Heat Credits} = \Delta\text{CO2e}_{\text{thermal}} / 1,000,000 \times \text{CreditValue}$$

$$\text{CreditValue} = 1 \text{ credit/tonneCO2e}$$

$$1,000,000 = \text{Grams per metric ton.}$$

$$\Delta\text{CO2e}_{\text{direct}} = \text{Annual CO2e reduction [g] due to equipment replacement} = \text{CO2e}_{\text{base}} - \text{CO2e}_{\text{HP}}$$

$$\text{CO2e}_{\text{base}} = \text{Annual CO2e emissions [g] from baseline pool water heater}$$

If baseline fuel is known:

$$\text{Oil: CO2e}_{\text{base}} = E_{\text{load}} / \eta_{\text{ave,oil}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})$$

$$\text{Propane: CO2e}_{\text{base}} = E_{\text{load}} / \eta_{\text{ave,LP}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})$$

$$\text{Natural Gas: CO2e}_{\text{base}} = (E_{\text{load}} / \eta_{\text{ave,NG}} \times \text{CI}_{\text{NG}}) / (1 - \text{TDL}_{\text{NG}})$$

If baseline fuel is unknown:

$$\text{CO2e}_{\text{base}} = ((\% \text{Oil} \times E_{\text{load}} \times (\text{CI}_{\text{oil}} + \text{CI}'_{\text{oil}})) / \eta_{\text{ave,oil}}) + ((\% \text{LP} \times E_{\text{load}} \times (\text{CI}_{\text{LP}} + \text{CI}'_{\text{LP}})) / \eta_{\text{ave,LP}}) + ((\% \text{NG} \times E_{\text{load}} \times \text{CI}_{\text{NG}}) / \eta_{\text{ave,NG}}) / (1 - \text{TDL}_{\text{NG}}) + ((\% \text{Elec} \times E_{\text{load}} \times \text{CI}_{\text{elec}}) / \eta_{\text{ave,elec}}) / (1 - \text{TDL}_{\text{elec}})$$

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 34). Pool water heating fuel mix is assumed to approximate domestic hot water fuel mix.⁴⁰⁴

$\eta_{ave,fuel}$ = Assumed average pool water heater efficiency by fuel (see Table 131)⁴⁰⁵

Table 131. Vermont Water Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Pool Water Heating Fuel | Fuel Mix | Average Efficiency ($\eta_{ave,fuel}$) |
|-------------------------|----------|--|
| Oil | 9% | 0.85 |
| Propane (LP) | 24% | 0.85 |
| Natural Gas | 23% | 0.85 |
| Electricity | 43% | 0.99 |

$$CO2e_{HP} = CO2e \text{ emissions from heat pump pool water heater [g]} = (E_{load} / COP_{HP} \times CI_{elec}) / (1 - TD_{elec})$$

COP_{HP} = Coefficient of performance (COP) of proposed heat pump pool water heater [dimensionless]. Use actual or assume 4.79 if unknown.⁴⁰⁶

Non-Thermal Sector CO2e Impacts: None

Common Inputs

$$E_{load} = \text{Annual pool water heating load [MJ]} =$$

$$= (MMBTU_{surface} + MMBTU_{reheat} + MMBTU_{evap} - MMBTU_{solar}) \times 1,055$$

$MMBTU_{surface}$ = Annual heating energy load contributed by convection/radiation heat losses via pool surface. Based on the hourly temperature for Springfield, Montpelier, Rutland, and Burlington, applied to a 36ft by 18ft pool kept at 82 °F from June 1 to September 30.

$$= 170.45 \text{ (no pool cover)}$$

$$= 141.18 \text{ (pool covered from 8pm to 8am)}$$

$$= 155.82 \text{ (pool cover use unknown)}^{407}$$

⁴⁰⁴ NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 104.

⁴⁰⁵ Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater, fossil fuel heater efficiency. “85% to be conservative - Allen Pools says 85 to 90%; Poultney pools said 82-84%. Find analysis information on Pool Calcs tab of document: Heat Pump Pool Water Heater Calcs_2021_Final version.xlsx” The efficiency of standard electric pool heaters is expected to be close to 100%.

⁴⁰⁶ Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. “The minimum required efficiency is COP 4.0 for all sizes of heat pump pool heaters. While we reviewed decreasing to minimum standards, the VT pool market shows a greater COP value. Poultney Pools offers Hayward Summit XL #SUMXL140 with a COP 5.7 at peak performance. Allen Pools offers Hayward Summit XL as well, for in ground pools. We found a weighted average of COP, based on the average air temperature during these months.”

⁴⁰⁷ A simple average is assumed in the absence of data on prevalence of pool cover use.

$MMBTU_{reheat}$ = Annual heating energy load contributed by heating the full volume of pool water. Based on heating a pool volume of 23,500 gallons from a temperature of 52 °F⁴⁰⁸ to 82 °F

$$= 5.87$$

$MMBTU_{evap}$ = Annual heating energy load contributed by evaporation. Based on the hourly temperature and relative humidity values for Springfield, Montpelier, Rutland, and Burlington, applied to a 36ft by 18ft pool kept at 82 °F from June 1 to September 30.

$$= 2.15 \text{ (no pool cover)}$$

$$= 2.13 \text{ (pool covered from 8pm to 8am)}$$

$$= 2.14 \text{ (pool cover use unknown)}$$

$MMBTU_{solar}$ = Annual solar heat gain. Based on Global Horizontal Incidence modified to account for cloud cover and a solar absorptance factor of 0.77.⁴⁰⁹

$$= 57.08 \text{ (with or without pool cover)}$$

$$1,055 = \text{MJ per MMBTU}$$

CI = Carbon intensity [g CO₂e/MJ] of fuel (see Table 1 in Section 1.3.2)

CI' = Carbon intensity adder for delivery of fuel to end user [g CO₂e/MJ] (see Table 3 in Section 1.3.3)

TDL = Transmission and distribution losses (see Table 3 in Section 1.3.3)

MEASURE LIFE

The expected measure life is assumed to be 5 years.⁴¹⁰

MEASURE COST

The retrofit cost of a heat pump pool water heater is \$4,200.⁴¹¹

PROGRAM DATA TRACKING RECOMMENDATIONS

The following variables should be tracked for this measure:

- Fuel type and efficiency of existing pool heater (η_{base})
- COP of proposed heat pump water heater (COP_{hp})
- Use of pool cover and estimated hours of use

⁴⁰⁸ Average ground water temperature for Burlington, Montpelier, Rutland, and Springfield, VT from U.S. DOE Standard Building America DHW Schedules, May 2014

⁴⁰⁹ Buscemi, A. et al. *A Novel Model to Assess the Energy Demand of Outdoor Swimming Pools*. Energy Conversion and Management, 2024.

⁴¹⁰ Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. "5 years is based on the parts warranty on heat pump pool water heaters."

⁴¹¹ Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. "This is the actual cost of a Hayward Heat Pump Pool Water Heater. Find further information on Assumptions tab of document: Heat Pump Pool Water Heater Calcs_2021_Final version.xlsx"

ENERGY CODES AND STANDARDS

Minimum efficiencies for pool heaters are prescribed in federal standard 10 CFR 430.32(k)(2).

4. FUEL MEASURES

4.1 LIQUID AND GASEOUS FUELS

4.1.1 GASEOUS HYDROGEN FROM DEDICATED RENEWABLES

CHS Measure ID: ALL_FUEL_HYD

Market Sector: All

End Use: Alternative Fuels

Applicable Building Types: All

Decarbonization Pathways: Alternative Fuels

Applicable Feedstocks: Gaseous hydrogen from dedicated renewables

MEASURE DESCRIPTION

This measure involves the replacement of gaseous hydrogen produced through steam-methane reforming (SMR) without carbon capture and sequestration, commonly referred to as “grey hydrogen,” used in the thermal sector with gaseous hydrogen produced through electrolysis powered from dedicated renewables, commonly referred to as “green hydrogen.” Hydrogen produced through SMR or electrolysis are chemically identical and can be directly substituted for one another in thermal enduses; this measure assumes that the green hydrogen is used as a drop-in replacement for an existing use of grey hydrogen. This measure characterizes gaseous green hydrogen produced through polymer electrolyte membrane (PEM) electrolysis at a centralized plant. This measure does not characterize the liquid forms of grey and green hydrogen, which must undergo additional energy and carbon intensive steps in production, including liquefaction and cryogenic storage, and is susceptible to boil-off of hydrogen during transport and storage.

Greenhouse gas reductions associated with this measure are derived from the difference in carbon intensity values (gCO_{2e}/MJ) between SMR-produced gaseous hydrogen and gaseous green hydrogen.

Baseline Conditions

The baseline condition is the use of gaseous grey hydrogen produced through SMR in the thermal sector that is delivered to the end-user through truck delivery. Other baseline conditions are not characterized for this measure.

Proposed Conditions

The proposed condition is the use of gaseous green hydrogen used in the thermal sector that is distributed to end users through a truck delivery service. Green hydrogen production pathways (and therefore carbon intensity values) include feedstock collection, fuel production, and transport of fuels to distributors. Emissions resulting from the distribution of fuels from the distributor to the end user are presumed equal between the proposed and baseline conditions since truck delivery is assumed in both.

ELIGIBILITY CRITERIA

This measure characterizes gaseous hydrogen used in the thermal sector under a certain set of conditions. Specifically:

- The carbon intensity value for green hydrogen is characterized for PEM electrolysis using dedicated renewables as the energy source. Other pathways, such as nuclear-powered electrolysis are not eligible for this measure.

This measure does not characterize the use of hydrogen in the thermal sector that does not meet this above condition.

Certain uses of hydrogen are not eligible for clean heat credits:

- Hydrogen distributed to an electricity generating unit (EGU) is not part of the thermal sector and therefore is not eligible for clean heat credits.
- Hydrogen distributed to an industrial facility must be verified as being used in the thermal sector. Hydrogen itself used as a material feedstock in production of a good or otherwise used outside of the thermal sector is ineligible for clean heat credits.

DECARBONIZATION SUMMARY

Table 132 provides the estimated 2025 decarbonization range for replacement of grey hydrogen with green hydrogen under varying blends of green and conventional hydrogen. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Table 132. Green Hydrogen CO₂e Reductions

| Portion of Green Hydrogen in Delivered Hydrogen | CO ₂ e Reduction per Kilogram [gCO ₂ e/kg] in 2025 |
|---|--|
| 20% Green Hydrogen | 2,076 |
| 40% Green Hydrogen | 4,151 |
| 60% Green Hydrogen | 6,227 |
| 80% Green Hydrogen | 8,302 |
| 100% Green Hydrogen | 10,378 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

$$\text{CO}_2\text{e (g CO}_2\text{e)} = (CI_{\text{base}} - CI_{\text{prop}}) \times E$$

CI_{base} = Grey hydrogen carbon intensity value (gCO₂e/MJ). Varies by year; see Table 1 in Section 1.3.2.

CI_{prop} = Green hydrogen carbon intensity value (gCO₂e/MJ). Varies by year; see Table 1 in Section 1.3.2.

If a blend of green and grey hydrogen is used, calculate the correct CI_{prop} using the following formula.

$$CI_{\text{prop}} = (\%GH_2 \times EF_{GH_2}) + ((1 - \%GH_2) \times EF_{CH_2})$$

$\%GH_2$ = The percentage of green hydrogen, by volume, within the delivered fuel.

CI_{GH_2} = The carbon intensity value for green hydrogen.

Cl_{CH_2} = The carbon intensity value for grey hydrogen.

E = The total energy of the hydrogen delivered to the end-user in units of megajoules (MJ).

Energy Impacts Algorithms

$$E = W_{delivered} \times LHV$$

Input Variable Definitions

$W_{delivered}$ = The total weight of gaseous hydrogen that is delivered to the end-user in kilograms.

LHV = Lower Heating Value of the hydrogen in units of MJ/kg. Grey and green hydrogen have the same LHV, 129.48 MJ/kg.¹

Measure Life

Green hydrogen is not subject to a measure life, as the measure characterization is based on the weight of hydrogen that is delivered to an end-user and used in the thermal sector.

Measure Cost

The incremental cost of green hydrogen over grey hydrogen. Use actual costs.

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Weight of delivered hydrogen gas to the end user
- Percentage of green hydrogen in total delivered hydrogen, by weight

ENERGY CODES AND STANDARDS

None.

¹ Wang, Michael, Elgowainy, Amgad, Lu, Zifeng, et al. Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model © (2023rev1 Release). Computer Software. USDOE Office of Energy Efficiency and Renewable Energy (EERE). 09 Oct. 2023. Web. doi:10.11578/GREET-Net-2023/dc.20230907.2. Retrieved from <https://greet.anl.gov/>

4.1.2 BIOMETHANE

CHS Measure ID: ALL_FUEL_BMN

Market Sector: All

End Use: Alternative Fuels

Applicable Building Types: All

Decarbonization Pathways: Alternative Fuels

Applicable Feedstocks: Animal waste, landfill gas, wastewater treatment plant sludge, and fats, oils, and greases

MEASURE DESCRIPTION

This measure involves the replacement of natural gas used in the thermal sector with biomethane. Biomethane, also known as renewable natural gas, is biogas that has been upgraded to be fully interchangeable with fossil natural gas. Biomethane can be directly substituted for fossil natural gas in thermal enduses; this measure assumes that biomethane is used as a drop-in replacement for an existing thermal use of natural gas.

This measure characterizes four distinct pathways for the production of biomethane from waste products (animal waste, landfill gas, wastewater treatment plant sludge, and fats, oils, and greases). Greenhouse gas reductions associated with this measure are derived from the difference in carbon intensity values (gCO₂e/MJ) between natural gas and biomethane.

Biomethane production pathways (and therefore carbon intensity values) include feedstock collection, fuel production, and transport of fuels to distributors. The distribution of fuels from the distributor to the end user is accounted for in the Decarbonization and Energy Impacts Algorithms.

Baseline Conditions

The baseline condition is the use of natural gas in the thermal sector that is delivered to the end-user through the Vermont natural gas distribution system.

Proposed Conditions

The proposed condition is the use of biomethane in the thermal sector that is delivered to the end-user through the Vermont natural gas distribution system.

ELIGIBILITY CRITERIA

This measure characterizes biomethane used in the thermal sector under a certain set of conditions. Specifically:

- Biomethane carbon intensity values are characterized for production pathways that reside within North America. Finished biomethane or feedstocks used in production of biomethane that are imported from outside North America are not eligible for this measure.
- Biomethane feedstocks not listed as one of the characterized pathways are not eligible for this measure.
- For biomethane to be eligible for this measure, it must be distributed to an end user through the Vermont natural gas distribution system. Biomethane distributed through other channels is not eligible for this measure.

This measure does not characterize the use of biomethane in the thermal sector that does not meet these above conditions.

Certain uses of biomethane are not eligible for clean heat credits:

- Biomethane distributed to an electricity generating unit (EGU) is not part of the thermal sector and therefore is not eligible for clean heat credits.

DECARBONIZATION SUMMARY

Table 133 provides the estimated 2025 decarbonization range for the proportional replacement of natural gas with biomethane in the Vermont natural gas distribution system from each of the four characterized feedstocks under varying proportionality. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein (e.g., natural gas proportionally replaced with biomethane from a mix of pathways).

Table 133. Biomethane CO₂e Reductions

| Portion of Biomethane in Distribution System | CO ₂ e Reduction per 100 Cubic Feet [gCO ₂ e/CCF] in 2025 by Fuel Pathway | | | |
|--|---|--------------|-----------------------------------|-------------------------|
| | Animal Waste | Landfill Gas | Wastewater Treatment Plant Sludge | Fats, Oils, and Greases |
| 20% Biomethane | 2,680 | 1,201 | 1,555 | 797 |
| 40% Biomethane | 5,359 | 2,403 | 3,110 | 1,593 |
| 60% Biomethane | 8,039 | 3,604 | 4,666 | 2,390 |
| 80% Biomethane | 10,719 | 4,805 | 6,221 | 3,187 |
| 100% Biomethane | 13,399 | 6,007 | 7,776 | 3,983 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

$$CO_2e \text{ (gCO}_2e) = (CI_{base} - CI_{prop}) \times E$$

CI_{base} = Natural gas carbon intensity value (gCO₂e/MJ). Varies by year; see Table 1 in Section 1.3.2.

CI_{prop} = Biomethane carbon intensity value (gCO₂e/MJ), based on fuel pathway. Varies by year; see Table 1 in Section 1.3.2. If a blend of biomethane from various pathways is used, then develop a weighted average by volume.

E = The total energy of the biomethane delivered to the end-user in megajoules.

Energy Impacts Algorithms

$$E = (V_{delivered} \times \%Thermal \times P_{RNG} \times LHV \times (1 + PLL))$$

Input Variable Definitions

$V_{delivered}$ = The total volume of gas that is delivered to the end-user in units of 100 cubic feet.

$\%Thermal$ = Share of gas used in the thermal sector. Assume 100%. {

P_{RNG} = The portion of gas that is biomethane (defined as a percentage by volume of all gas in the distribution system).

LHV = Lower Heating Value of the fuel in units of MJ/CCF. Natural gas and biomethane have the same LHV, 103.71 MJ/CCF.²

PLL = Pipeline loss factor, 0.09%³

Measure Life

Biomethane as a clean heat measure is not subject to a measure life, as the measure characterization is based on the volume of biomethane that is delivered to an end-user and used in the thermal sector.

Measure Cost

The incremental cost of biomethane over natural gas. Use actual costs.

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Volume of delivered gas to the end-user
- Percentage of biomethane in the Vermont natural gas distribution system

ENERGY CODES AND STANDARDS

None.

² Wang, Michael, Elgowainy, Amgad, Lu, Zifeng, et al. Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model © (2023rev1 Release). Computer Software. USDOE Office of Energy Efficiency and Renewable Energy (EERE). 09 Oct. 2023. Web. doi:10.11578/GREET-Net-2023/dc.20230907.2. Retrieved from <https://greet.anl.gov/>

³ Ibid.

4.1.3 BIODIESEL

CHS Measure ID: ALL_FUEL_BD

Market Sector: All

End Use: Alternative Fuels

Applicable Building Types: All

Decarbonization Pathways: Alternative Fuels

Applicable Feedstocks: Soybean oil, canola oil, corn oil, and used cooking oil

MEASURE DESCRIPTION

This measure involves the replacement of fuel oil #2 used in the thermal sector with biodiesel. Biodiesel is a liquid renewable fuel manufactured through the transesterification of biological feedstocks such as waste vegetable oils.⁴ This measure assumes that biodiesel is used as a drop-in replacement for an existing thermal use of fuel oil #2. While this measure assumes that biodiesel is used as a drop-in replacement, it is important to note that biodiesel is chemically different from fuel oil #2 and exhibits a number of different characteristics that mean it is not necessarily possible to use biodiesel as a drop-in replacement in all cases without additional steps.⁵ Replacement of fuel oil #2 with pure biodiesel may require equipment modifications; biodiesel can be blended with fuel oil #2 at various concentrations, and certain concentrations may not require equipment modifications.

This measure characterizes four distinct pathways for the production of biodiesel: three pathways for biodiesel from purpose-grown crops (soybeans, canola, and corn) as well as one biodiesel pathway from a waste product (used cooking oil).

Greenhouse gas reductions associated with this measure are derived from the difference in carbon intensity values (gCO_{2e}/MJ) between fuel oil #2 and biodiesel.

Baseline Conditions

The baseline condition is the use of fuel oil #2 in the thermal sector that is distributed to end users through a truck delivery service.

Proposed Conditions

The proposed condition is the use of biodiesel in the thermal sector that is distributed to end users through a truck delivery service. Biodiesel production pathways (and therefore carbon intensity values) include farming activities, crop applications (e.g., pesticides, herbicides, and fertilizers), feedstock collection, fuel production, and transport of fuels to distributors. The production pathways exclude impacts relating to land use changes and the biogenic carbon cycle. Emissions resulting from the distribution of fuels from the distributor to the end user are presumed equal between the proposed and baseline conditions since truck delivery is assumed in both.

⁴ U.S. Department of Energy Alternative Fuels Data Center. Accessed at: <https://afdc.energy.gov/fuels/biodiesel-production>

⁵ Gerverni, M., T. Hubbs and S. Irwin. "Biodiesel and Renewable Diesel: What's the Difference?" *farmdoc daily* (13):22, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, February 8, 2023.

ELIGIBILITY CRITERIA

This measure characterizes biodiesel used in the thermal sector under a certain set of conditions. Specifically:

- Biodiesel carbon intensity values are characterized for production pathways that reside within North America. Finished biodiesel or feedstocks used in production of biodiesel that are imported from outside North America are not eligible for this measure.
- Biodiesel feedstocks not listed as one of the characterized pathways are not eligible for this measure.
- For biodiesel to be eligible for this measure, it must be distributed to an end user through a truck delivery service. Biodiesel distributed through other channels is not eligible for this measure.

Certain uses of biodiesel are not eligible for clean heat credits:

- Biodiesel used for electrical generation is not eligible.
- Biodiesel distributed to an industrial facility should be verified as being used in process or space heating. Biodiesel used as a material feedstock in production of a good or otherwise not used as a heating fuel is ineligible for this measure.

DECARBONIZATION SUMMARY

Table 134 provides the estimated 2025 decarbonization range for replacement of fuel oil #2 with biodiesel from each of the four characterized feedstocks under varying proportionality. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Table 134. Biodiesel CO₂e Reductions

| Biodiesel Blend | CO ₂ e Reduction per Gallon [gCO ₂ e/gallon] in 2025 by Fuel Pathway | | | |
|-----------------------|--|------------|----------|------------------|
| | Soybean Oil | Canola Oil | Corn Oil | Used Cooking Oil |
| 20% Biodiesel (B20) | 1,517 | 1,308 | 1,204 | 1,871 |
| 40% Biodiesel (B40) | 2,992 | 2,579 | 2,374 | 3,690 |
| 60% Biodiesel (B60) | 4,424 | 3,813 | 3,511 | 5,456 |
| 80% Biodiesel (B80) | 5,815 | 5,012 | 4,614 | 7,171 |
| 100% Biodiesel (B100) | 7,163 | 6,173 | 5,684 | 8,833 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

$$\text{CO}_2\text{e (gCO}_2\text{e)} = (CI_{\text{base}} - CI_{\text{prop}}) \times E$$

CI_{base} = Fuel oil #2 carbon intensity value (gCO₂e/MJ). Varies by year; see Table 1 in Section 1.3.2.

CI_{prop} = Biodiesel carbon intensity value (gCO₂e/MJ), based on fuel pathway. Varies by year; see Table 1 in Section 1.3.2. If a blend of biodiesel from various pathways is used, then develop a weighted average by volume. If a biodiesel blend (e.g., B20 – 20% biodiesel and 80% fuel oil #2) is used, refer to Table 135 for the appropriate CI_{prop} . If the delivered biodiesel blend is not shown, calculate the correct CI_{prop} using the following formula.

$$CI_{prop} = (\%BD \times EF_{BD100}) + ((1 - \%BD) \times EF_{base})$$

%BD = The percentage of biodiesel, by volume, within the fuel.

CI_{BD100} = The carbon intensity value for 100% biodiesel.

E = The total energy of the biodiesel delivered to the end-user in megajoules.

Energy Impacts Algorithms

$$E = (V_{BD} \times LHV_{BD})$$

Input Variable Definitions

V_{BD} = The total volume of biodiesel that is delivered to the end-user in gallons.

LHV_{BD} = Lower Heating Value of biodiesel in units of MJ/gallon.⁶ Refer to Table 135 for the appropriate LHV for the biodiesel blend delivered to the end user. If the delivered biodiesel blend is not shown, calculate the correct LHV_{BD} using the following formula.

$$LHV_{BD} = (\%BD \times LHV_{BD100}) + ((1 - \%BD) \times LHV_{oil})$$

LHV_{BD100} = Lower Heating Value of a 100% biodiesel fuel, 126.21 MJ/gal.

LHV_{oil} = Lower Heating Value of fuel oil #2, 135.52 MJ/gal.

Table 135. Lower Heating Values and Carbon Intensity Values for Biodiesel Blends

| Biodiesel Blend | LHV _{BD} [MJ/gal] | 2025 Carbon Intensity Values [gCO _{2e} /MJ] | | | |
|-----------------------|----------------------------|--|----------|--------|------|
| | | All BD fuels | Soybeans | Canola | Corn |
| 20% Biodiesel (B20) | 133.66 | 72.1 | 73.7 | 74.5 | 69.5 |
| 40% Biodiesel (B40) | 131.80 | 60.8 | 63.9 | 65.4 | 55.5 |
| 60% Biodiesel (B60) | 129.93 | 49.4 | 54.1 | 56.4 | 41.5 |
| 80% Biodiesel (B80) | 128.07 | 38.1 | 44.3 | 47.4 | 27.5 |
| 100% Biodiesel (B100) | 126.21 | 26.7 | 34.5 | 38.4 | 13.5 |

Measure Life

Biodiesel as a clean heat measure is not subject to a measure life, as the measure characterization is based on the volume of biodiesel that is delivered to an end-user and used in the thermal sector.

Measure Cost

The incremental cost of biodiesel over fuel oil #2. Use actual costs.

⁶ Wang, Michael, Elgowainy, Amgad, Lu, Zifeng, et al. Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model © (2023rev1 Release). Computer Software. USDOE Office of Energy Efficiency and Renewable Energy (EERE). 09 Oct. 2023. Web. doi:10.11578/GREET-Net-2023/dc.20230907.2. Retrieved from <https://greet.anl.gov/>

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Volume of delivered biodiesel to the end-user
- Share of delivered biodiesel that is used in the thermal sector

ENERGY CODES AND STANDARDS

None.

4.1.4 RENEWABLE DIESEL

CHS Measure ID: ALL_FUEL_RD

Market Sector: All

End Use: Alternative Fuels

Applicable Building Types: All

Decarbonization Pathways: Alternative Fuels

Applicable Feedstocks: Soybean oil, canola oil, corn oil, and used cooking oil

MEASURE DESCRIPTION

This measure involves the replacement of fuel oil #2 used in the thermal sector with renewable diesel. Renewable diesel is a liquid renewable fuel manufactured from biological feedstocks such as waste vegetable oils through any one of a number of different technology pathways.⁷ Renewable diesel is distinct from biodiesel and is chemically similar (though not identical) to fuel oil #2; renewable diesel is generally considered to be fully interchangeable with fuel oil #2,⁸ and this measure assumes that renewable diesel is used as a drop-in replacement for an existing thermal use of fuel oil #2.

The measure characterizes four distinct pathways for the production of renewable diesel: three pathways for renewable diesel from purpose-grown crops (soybean oil, canola oil, and corn oil) as well as one renewable diesel pathway from a waste product (used cooking oil). Greenhouse gas reductions associated with this measure are derived from the difference in lifecycle emission intensities (gCO_{2e}/MJ) between fuel oil #2 and renewable diesel.

Baseline Conditions

The baseline condition is the use of fuel oil #2 in the thermal sector that is distributed to end users through a truck delivery service.

Proposed Conditions

The proposed condition is the use of renewable diesel in the thermal sector that is distributed to end users through a truck delivery service. Renewable diesel production pathways (and therefore carbon intensity values) include farming activities, crop applications (e.g., pesticides, herbicides, and fertilizers), feedstock collection, fuel production, and transport of fuels to distributors. The production pathways exclude impacts relating to land use changes and the biogenic carbon cycle. Emissions resulting from the distribution of fuels from the distributor to the end user are presumed equal between the proposed and baseline conditions since truck delivery is assumed in both.

ELIGIBILITY CRITERIA

This measure characterizes renewable diesel used in the thermal sector under a certain set of conditions. Specifically:

⁷ U.S. Department of Energy Alternative Fuels Data Center. Accessed at: <https://afdc.energy.gov/fuels/renewable-diesel>

⁸ Gerveri, M., T. Hubbs and S. Irwin. "Biodiesel and Renewable Diesel: What's the Difference?" *farmdoc daily* (13):22, Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, February 8, 2023.

- Renewable diesel carbon intensity values are characterized for production pathways that reside within North America. Finished renewable diesel or feedstocks used in production of renewable diesel that are imported from outside North America are not eligible for this measure.
- Renewable diesel feedstocks not listed as one of the characterized pathways are not eligible for this measure.
- For renewable diesel to be eligible for this measure, it must be distributed to an end user through a truck delivery service. Renewable diesel distributed through other channels is not eligible for this measure.

Certain uses of renewable diesel are not eligible for clean heat credits:

- Renewable diesel used for electrical generation is not eligible.
- Renewable diesel distributed to an industrial facility should be verified as being used in process or space heating. Renewable diesel used as a material feedstock in production of a good or otherwise not used as a heating fuel is ineligible for this measure.

DECARBONIZATION SUMMARY

Table 136 provides the estimated 2025 decarbonization range for replacement of fuel oil #2 with renewable diesel from each of the four characterized feedstocks. These estimates are not inclusive of all eligible conditions; other conditions may be calculated from the algorithms herein.

Table 136. Renewable Diesel CO₂e Reductions

| | CO ₂ e Reduction per Gallon [gCO ₂ e/gallon] in 2025 by Fuel Pathway | | | |
|------------------|--|------------|----------|------------------|
| | Soybean Oil | Canola Oil | Corn Oil | Used Cooking Oil |
| Renewable Diesel | 6,941 | 5,637 | 5,277 | 8,591 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

$$CO_{2e} \text{ (gCO}_{2e}\text{)} = (ECI_{base} - CI_{prop}) \times E$$

CI_{base} = Fuel oil #2 carbon intensity value (gCO₂e/MJ). Varies by year; see Table 1 in Section 1.3.2.

CI_{prop} = Renewable diesel carbon intensity value (gCO₂e/MJ), based on fuel pathway. Varies by year; see Table 1 in Section 1.3.2. If a blend of renewable diesel from various pathways is used, then develop a weighted average by volume.

E = The total energy of the renewable diesel delivered to the end-user in megajoules.

Energy Impacts Algorithms

$$E = (V_{RD} \times LHV_{RD})$$

Input Variable Definitions

V_{RD} = The total volume of renewable diesel that is delivered to the end-user in gallons.

LHV_{RD} = Lower Heating Value of renewable diesel in units of MJ/gallon, 129.65 MJ/gal.⁹

Measure Life

Renewable diesel as a clean heat measure is not subject to a measure life, as the measure characterization is based on the volume of renewable diesel that is delivered to an end-user and used in the thermal sector.

Measure Cost

The incremental cost of renewable diesel over fuel oil #2. Use actual costs.

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Volume of delivered renewable diesel to the end-user
- Share of renewable diesel that is used in the thermal sector

ENERGY CODES AND STANDARDS

None.

⁹ Wang, Michael, Elgowainy, Amgad, Lu, Zifeng, et al. Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model © (2023rev1 Release). Computer Software. USDOE Office of Energy Efficiency and Renewable Energy (EERE). 09 Oct. 2023. Web. doi:10.11578/GREET-Net-2023/dc.20230907.2. Retrieved from <https://greet.anl.gov/>

4.1.5 RENEWABLE PROPANE

CHS Measure ID: ALL_FUEL_RP

Market Sector: All

End Use: Alternative Fuels

Applicable Building Types: All

Decarbonization Pathways: Alternative Fuels

Applicable Feedstocks: Not specified

MEASURE DESCRIPTION

This measure involves the replacement of fossil-derived propane (“fossil propane”) used in the thermal sector with renewable propane. Renewable propane is a renewable fuel manufactured from biological feedstocks such as natural fats or vegetable oils through a HEFA (hydrogenated esters and fatty acids) process.^{10,11} Renewable propane is chemically identical to fossil propane and therefore is considered to be fully interchangeable with fossil propane. This measure assumes that renewable propane is used as a drop-in replacement for an existing thermal use of fossil propane.

Unlike the other measures described in this section, this measure does not characterize specific pathways for the production of renewable propane. Tools for lifecycle analysis of renewable propane are currently in their infancy and a full lifecycle analysis for renewable propane specific to the CHS has not been completed. Instead, this measure provides a general characterization of renewable propane that can be used if a statutorily compliant carbon intensity for renewable propane becomes available.

Like other measures presented in this section, greenhouse gas reductions associated with this measure are derived from the difference in lifecycle emission intensities (gCO₂e/MJ) between fossil propane and renewable propane.

Baseline Conditions

The baseline condition is the use of fossil propane in the thermal sector that is distributed to end users through a truck delivery service.

Proposed Conditions

The proposed condition is the use of renewable propane in the thermal sector that is distributed to end users through a truck delivery service. Emissions resulting from the distribution of fuels from the distributor to the end user are presumed equal between the proposed and baseline conditions since truck delivery is assumed in both.

ELIGIBILITY CRITERIA

This measure characterizes renewable propane used in the thermal sector under a certain set of conditions. Specifically:

¹⁰ U.S. Department of Energy Alternative Fuels Data Center. Accessed at: <https://afdc.energy.gov/fuels/propane-renewable>

¹¹ Note that while multiple technology pathways and feedstocks are theoretically possible for the production of renewable propane, our understanding is that all renewable propane currently produced uses the HEFA process.

- To use this measure, a statutorily compliant carbon intensity value must be used in conjunction with this measure characterization. The Vermont Public Utility Commission has determined that the placeholder value presented in Section 1.3.2 is not statutorily compliant and therefore may not be used.
- For renewable propane to be eligible for this measure, it must be distributed to an end user through a truck delivery service. Renewable propane distributed through other channels is not eligible for this measure.

Certain uses of renewable propane are not eligible for clean heat credits:

- Renewable propane used for electrical generation is not eligible.
- Renewable propane distributed to an industrial facility should be verified as being used in process or space heating. Renewable propane used as a material feedstock in production of a good or otherwise not used as a heating fuel is ineligible for this measure.

DECARBONIZATION SUMMARY

Table 137 provides the estimated 2025 decarbonization range for replacement of fossil propane with renewable propane using the placeholder renewable propane carbon intensity value presented in Section 1.3.2. This value is not statutorily compliant and is presented for comparative purposes only.

Table 137. Renewable Propane CO₂e Reductions

| | CO ₂ e Reduction per Gallon [gCO ₂ e/gallon] in 2025 |
|-------------------|--|
| Renewable Propane | 3,607 |

DECARBONIZATION AND ENERGY IMPACTS ALGORITHMS

$$\text{CO}_2\text{e (gCO}_2\text{e)} = (CI_{\text{base}} - CI_{\text{prop}}) \times E$$

CI_{base} = Fossil propane carbon intensity value (gCO₂e/MJ). Varies by year; see Table 1 in Section 1.3.2

CI_{prop} = Renewable propane carbon intensity value (gCO₂e/MJ). See Table 1 in Section 1.3.2. If a renewable propane blend (e.g. 20% renewable propane and 80% fossil propane) is used, calculate the correct CI_{prop} using the following formula.

$$CI_{\text{prop}} = (\%RP \times EF_{RP100}) + ((1 - \%RP) \times EF_{\text{base}})$$

$\%RP$ = The percentage of renewable propane, by volume, within the fuel.

CI_{BD100} = The carbon intensity value for 100% renewable propane.

E = The total energy of the renewable propane delivered to the end-user in megajoules.

Energy Impacts Algorithms

$$E = (V_{RP} \times LHV_{RP})$$

Input Variable Definitions

V_{RP} = The total volume of renewable propane that is delivered to the end-user in gallons.

LHV_{RP} = Lower Heating Value of the fuel in units of MJ/gal. Fossil propane and renewable propane have the same LHV, 88.89 MJ/gal.¹²

Measure Life

Renewable propane as a clean heat measure is not subject to a measure life, as the measure characterization is based on the volume of renewable propane that is delivered to an end-user and used in the thermal sector.

Measure Cost

The incremental cost of renewable propane over fossil propane. Use actual costs.

PROGRAM DATA TRACKING RECOMMENDATIONS

The key input variables for this measure are the following:

- Volume of delivered renewable propane to the end-user
- Share of delivered renewable propane that is used in the thermal sector

ENERGY CODES AND STANDARDS

None.

¹² Wang, Michael, Elgowainy, Amgad, Lu, Zifeng, et al. Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model ® (2023rev1 Release). Computer Software. USDOE Office of Energy Efficiency and Renewable Energy (EERE). 09 Oct. 2023. Web. doi:10.11578/GREET-Net-2023/dc.20230907.2. Retrieved from <https://greet.anl.gov/>