A close-up of a building

Description automatically generated

Vermont Clean Heat Standard TRM

Installed Measure Characterizations

Draft

September 17, 2024

Contents

[1. Overview 4](#_Toc177481953)

[1.1 Purpose of the TRM 4](#_Toc177481954)

[1.2 Glossary 4](#_Toc177481955)

[1.3 Common Assumptions 5](#_Toc177481956)

[1.4 Custom Measures 7](#_Toc177481957)

[2. Commercial/Industrial Installed Measures 8](#_Toc177481958)

[2.1 Appliances 8](#_Toc177481959)

[2.2 Building Envelope 19](#_Toc177481960)

[2.3 Domestic Hot Water 32](#_Toc177481961)

[2.4 HVAC 57](#_Toc177481962)

[2.5 Miscellaneous 101](#_Toc177481963)

[3. Residential Installed Measures 106](#_Toc177481964)

[3.1 Appliances 106](#_Toc177481965)

[3.2 Building Envelope 117](#_Toc177481966)

[3.3 Domestic Hot Water 132](#_Toc177481967)

[3.4 HVAC 154](#_Toc177481968)

[3.5 Miscellaneous 214](#_Toc177481969)

[4. Fuel Measures 223](#_Toc177481970)

Acknowledgements

The TRM is a technical document developed by Opinion Dynamics pursuant to its statutorily defined role as “a third-party consultant responsible for developing clean heat measure characterizations and relevant assumptions, including CO2e lifecycle emissions analyses.”[[1]](#footnote-1) The TRM was greatly informed by discussions in the 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.

# Overview

## 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.

### Deemed Savings

## Glossary

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

* **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).
* **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:**[[2]](#footnote-2) Materials used directly in manufacturing processes and transformed into an intermediate or finished material.[[3]](#footnote-3) For biofuels, a material input to fuel production such as an agricultural or waste product.
* **Firewood:**[[4]](#footnote-4) Untreated or treated 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.

## Common Assumptions

### Lifecycle Emissions Schedule

Table 1 presents the lifecycle emissions rate schedule.

Table 1. Lifecycle Emissions Rate Schedule

| Fuel | Lifecycle Average Carbon Intensity Value (gCO2e/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 | 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 | 73.3 | 73.7 | 73.8 | 73.6 | 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 |
| 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 from SMR | 92.9 | 92.9 | 91.1 | 91.1 | 91.1 | 91.1 | 91.1 | 86.5 | 86.5 | 86.5 | 86.5 | 86.5 | 85.6 | 85.6 | 85.6 | 85.6 | 85.6 | 85.4 | 85.4 | 85.4 | 85.4 | 85.4 | 85.2 | 85.2 | 85.2 | 85.2 | 85.2 | 84.6 |
| Hydrogen from dedicated renewablesc | 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 | 15.2 | 15.2 | 15.1 | 15.1 | 15.1 | 15.1 | 15.1 | 14.7 | 14.7 | 14.7 | 14.7 | 14.7 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 14.5 |
| Biomethane from landfill gas | 7.7 | 7.7 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 4.2 | 4.2 | 4.2 | 4.2 | 4.2 | 3.8 | 3.8 | 3.8 | 3.8 | 3.8 | 3.6 | 3.6 | 3.6 | 3.6 | 3.6 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.3 |
| Biomethane from fats, oils, and greases | 29.0 | 29.0 | 26.2 | 26.2 | 26.2 | 26.2 | 26.2 | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 17.6 | 17.6 | 17.6 | 17.6 | 17.6 | 17.2 | 17.2 | 17.2 | 17.2 | 17.2 | 16.6† |
| Biomethane from wastewater | 40.3 | 40.3 | 37.6 | 37.6 | 37.6 | 37.6 | 37.6 | 30.2 | 30.2 | 30.2 | 30.2 | 30.2 | 29.0 | 29.0 | 29.0 | 29.0 | 29.0 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.2 | 28.2 | 28.2 | 28.2 | 28.2 | 27.6† |
| Biodiesel from soybeans | 26.4 | 26.4 | 25.9 | 25.9 | 25.9 | 25.9 | 25.9 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 24.8 | 24.8 | 24.8 | 24.8 | 24.8 | 24.7 | 24.7 | 24.7 | 24.7 | 24.7 | 24.7 | 24.7 | 24.7 | 24.7 | 24.7 | 24.6† |
| Biodiesel from canola | 25.8 | 25.8 | 25.5 | 25.5 | 25.5 | 25.5 | 25.5 | 24.6 | 24.6 | 24.6 | 24.6 | 24.6 | 24.4 | 24.4 | 24.4 | 24.4 | 24.4 | 24.4 | 24.4 | 24.4 | 24.4 | 24.4 | 24.3 | 24.3 | 24.3 | 24.3 | 24.3 | 24.2† |
| Biodiesel from corn | 9.9 | 9.9 | 9.3 | 9.3 | 9.3 | 9.3 | 9.3 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.8 |
| Biodiesel from used cooking oil | 14.8 | 14.8 | 14.3 | 14.3 | 14.3 | 14.3 | 14.3 | 13.3 | 13.3 | 13.3 | 13.3 | 13.3 | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.6 |
| Renewable diesel from soybeans | 32.7 | 32.7 | 32.2 | 32.2 | 32.2 | 32.2 | 32.2 | 31.0 | 31.0 | 31.0 | 31.0 | 31.0 | 30.8 | 30.8 | 30.8 | 30.8 | 30.8 | 30.8 | 30.8 | 30.8 | 30.8 | 30.8 | 30.7 | 30.7 | 30.7 | 30.7 | 30.7 | 30.6† |
| Renewable diesel from canola | 32.3 | 32.3 | 31.9 | 31.9 | 31.9 | 31.9 | 31.9 | 30.9 | 30.9 | 30.9 | 30.9 | 30.9 | 30.7 | 30.7 | 30.7 | 30.7 | 30.7 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.4† |
| Renewable diesel from corn | 12.3 | 12.3 | 11.8 | 11.8 | 11.8 | 11.8 | 11.8 | 10.8 | 10.8 | 10.8 | 10.8 | 10.8 | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.5 |
| Renewable diesel from used cooking oil | 17.8 | 17.8 | 17.3 | 17.3 | 17.3 | 17.3 | 17.3 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 15.7 | 15.7 | 15.7 | 15.7 | 15.7 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.4 |
| Wood Fuels |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Wood chips | 31.6 | 31.6 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.2 | 31.2 | 31.2 | 31.2 | 31.2 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.1 | 31.0 |
| Wood pellets | 56.2 | 56.2 | 55.5 | 55.5 | 55.5 | 55.5 | 55.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.5 | 53.2 | 53.2 | 53.2 | 53.2 | 53.2 | 53.1 | 53.1 | 53.1 | 53.1 | 53.1 | 53.0 | 53.0 | 53.0 | 53.0 | 53.0 | 52.8 |
| Firewood, commercial | 32.0 | 32.0 | 31.9 | 31.9 | 31.9 | 31.9 | 31.9 | 31.8 | 31.8 | 31.8 | 31.8 | 31.8 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.7 | 31.6 |
| Firewood, non-commercial | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 |
| Eligible Emissions Limit |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Eligible emissions limit (reference value)a | N/A | N/A | 66.8 | 66.8 | 66.8 | 66.8 | 66.8 | 49.8 | 49.8 | 49.8 | 49.8 | 49.8 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 49.7 | 16.5 |

Note: Emissions rates are inclusive of both combustion and upstream emissions.

a Calculated in accordance with 30 V.S.A. § 8127(f).

† As currently analyzed, these liquid or gaseous fuels exceed the carbon intensity values as defined in 30 V.S.A. § 8127(f) and therefore would be nominally ineligible as clean heat measures beginning January 1, 2050, notwithstanding the provisions stated in 30 V.S.A. § 8127(f)(1)(C).

### Transmission and Distribution Losses and Carbon Intensity Adders

Carbon intensity adders for delivery of fuels to end user and transmission and distribution loss factors are required to calculate carbon reductions from many measures in this document. Table 2 presents those values for reference.

Table 2. Transmission and Distribution Losses and Carbon Intensity Adders

| Fuel Emissions Schedule Name | Carbon Intensity Adder (CI')  [gCO2e/MJ] | Transmission and Distribution Losses  (%) |
| --- | --- | --- |
| Fuel oil #2 | 0.2149 | N/A |
| Propane | 0.3276 | N/A |
| Natural gas | N/A | 1.4% |
| Grid electricity | N/A | 4.0% |
| Kerosene | 0.2221 | N/A |
| Wood, unspecified, non-commercial | 1.3777 | N/A |
| Wood, unspecified, commercial | 1.3777 | N/A |
| Wood chips | 1.9568 | N/A |
| Wood pellets | 1.9568 | N/A |
| Firewood, commercial | 0.7986 | N/A |

## Custom Measures

# Commercial/Industrial Installed Measures

## Appliances

### 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 3 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 3. Example C/I Heat Pump Clothes Dryer CO2e Reductions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Setting | ENERGY STAR Most Efficient? | Baseline Dryer Fuel | Lifetime CO2e Reductions,  Thermal Sector [g] | Lifetime CO2e Reductions,  Total [g] | Lifetime Credits |
| Coin-Operated Laundromat | No | Natural Gas |  |  |  |
| Propane |  |  |  |
| Yes | Natural Gas |  |  |  |
| Propane |  |  |  |
| Multifamily Common Area | No | Natural Gas |  |  |  |
| Propane |  |  |  |
| Yes | Natural Gas |  |  |  |
| Propane |  |  |  |
| On-Premise Laundromat | No | Natural Gas |  |  |  |
| Propane |  |  |  |
| Yes | Natural Gas |  |  |  |
| Propane |  |  |  |

#### Decarbonization and Energy Impact Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect + ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase dryer – CO2ehp dryer

CO2ebase dryer = Annual CO2e emissions [g] from baseline dryer

Propane: CO2ebase dryer = Ebase dryer x (CILP + CI’LP)

Natural gas: CO2ebase dryer = (Ebase dryer x CING) / (1 – TDLNG)

Ebase dryer = Baseline dryer energy usage = Load / CEFbase x 3.6

CEFbase = Minimum Combined Energy Factor (CEF) for vented gas dryer [lbs/kWh] = 2.84.[[5]](#footnote-5)

CO2ehp dryer = Annual CO2e emissions [g] from heat pump or hybrid dryer = (Ehp dryer x CIelec) / (1 – TDLelec)

Ehp dryer = Load / CEFhp x 3.6

CEFhp = CEF of the heat pump dryer unit based on type and ENERGY STAR level. [[6]](#footnote-6)

Table 4. Heat Pump Clothes Dryer CEFby Type (CEFhp)

| Technology | Size | CEFhp [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

Load = Annual clothes drying load [lbs] = Weight x Ncycles

Weight = Average clothes dryer load weight [lbs]. [[7]](#footnote-7)

Table 5. Average Load Weight by Dryer Size

| Dryer Size | Average Weight [lbs] |
| --- | --- |
| Standard (≥ 4.4 ft3) | 8.45 |
| Compact (< 4.4 ft3) | 3.00 |

Ncycles = Number of dryer cycles per year based on setting.

Table 6. Assumed Number of Dryer Cycles Per Year

| Setting | Ncycles |
| --- | --- |
| Coin-Operated Laundromat[[8]](#footnote-8) | 1,483 |
| Multifamily Common Area[[9]](#footnote-9) | 3,607 |
| On-Premise Laundromat[[10]](#footnote-10) | 1,074 |
| Other | Use actual |

Space Heating Impacts

If the primary space heating fuel is known:

Oil: ΔCO2eheat = (ΔEhl x (CIoil + CI’oil)) / ηave,oil

Propane: ΔCO2eheat = (ΔEhl x (CILP + CI’LP)) / ηave,LP

Natural Gas: ΔCO2eheat = ((ΔEhl x CING ) / ηave,NG)/(1-TDLNG)

Wood: CO2ewood = (ΔEhl x (CIwood + CI’wood)) / ηave,wood

If the primary space heating fuel is unknown:

ΔCO2eheat = ((%Oil x ΔEhl x (CIoil+CI’oil))/ηave,oil) + ((%LP x ΔEhl x (CILP+CI’LP)) /ηave,LP) + ((%NG x ΔEhl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x ΔEhl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x ΔEhl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 7)[[11]](#footnote-11)

ηave,fuel = Average heating efficiency for each fuel type [dimensionless] (see Table 7)[[12]](#footnote-12)

Table 7. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

|  |  |  |
| --- | --- | --- |
| Heating Fuel | Fuel % | Average Heating Efficiency (ηheat) |
| 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:

ΔEhl = (WHHF x %Conditioned)x ((HRbase x Ebase dryer) – (HRhp x Ehp dryer))

WHHF = Portion of reduced waste heat that results in increased heating = 0.558.[[13]](#footnote-13)

%Conditioned = Portion of buildings with dryer in conditioned space = 73%.[[14]](#footnote-14)

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool  = Space cooling impacts [g] = (ΔEcl x CIelec) /ηcool / (1 – TDLelec)

ηcool = Cooling system efficiency = 3.52.[[15]](#footnote-15)

Change in Cooling load:

ΔEcl = (WHCF x %Cool)x ((HRbase x Edryer,base) – (HRhp x Edryer,hp))

WHCF = Portion of waste heat that results in increased cooling= 0.188[[16]](#footnote-16)

%Cool = Percent of Vermont C/I facilities with cooling[[17]](#footnote-17)

Table 8. Percentage of C/I Customers with Cooling

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

**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 9. Portion of Dryer Heat Energy Remaining in Space

| Dryer Type | %HR [[18]](#footnote-18) |
| --- | --- |
| Vented | 5% |
| Ventless | 100% |

3.6 = MJ per kWh

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is estimated to be 10 years.[[19]](#footnote-19)

#### Measure Cost

The market opportunity incremental cost is $61 for ENERGY STAR units and $412 for ENERGY STAR Most Efficient Units.[[20]](#footnote-20)

#### 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 (Ncycles)

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.

### 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 10 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 10. Example Induction Cooktop CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| Existing Cooktop | Lifetime CO2e Reductions,  Thermal Sector [g] | Lifetime CO2e Reductions,  Total [g] | Lifetime Credits |
| Natural Gas |  |  |  |
| Propane |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 clean heat credit per metric ton of CO2e reductions.

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2einduction

CO2ebase = Annual CO2e emissions [g] of baseline cooktop:

If baseline dryer fuel is known:

Propane: CO2ebase = (Eload / ηbase,LP) x (CILP + CI’LP)

Natural Gas: CO2ebase = (Eload / ηbase,NG x CING)/(1 – TDLNG)

If baseline fuel is unknown:

CO2ebase = ((%LPcook x Eload)/ηbase,LP x(CILP+CI’LP)) + ((%NGcook x Ebase,NG x CING) /ηbase,NG)/(1-TDLNG) + ((%Eleccook x Ebase,elec x CIelec)/ηbase,elec)/(1-TDLelec)

%LPcook, etc. = Relative proportion of cooktop fuel in Vermont non-residential buildings. See Table 11.[[21]](#footnote-21)

ηbase,fuel = Baseline cooktop efficiency [[22]](#footnote-22)

Table 11. Assumed Cooktop Fuel Mix in Vermont Non-Residential Buildings and Baseline Cooktop Efficiency

|  |  |  |
| --- | --- | --- |
| Cooktop Fuel | %Fuelcook | ηbase,fuel |
| Propane | 7.5% | 34% |
| Natural Gas | 34.2% | 34% |
| Electricity | 57.3% | 75% |

CO2einduction = Annual CO2e emissions of electric induction cooktop

= (Eload / ηinduction x CIelec) / (1 – TDLelec)

ηinduction = 84%.[[23]](#footnote-23)

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

Eload = Annual cooking load [MJ] = EPD x Days

EPD = Energy per day [MJ] = Food x Eabs

Food = Pounds of food cooked per day [lb/day]. Use actual or assume 143 if unknown.[[24]](#footnote-24)

Eabs = ASTM energy to food ratio: the energy absorbed by the food during cooking [Btu/lb] = 130.[[25]](#footnote-25)

Days = Annual days of operation. Use actual or 326 days per year if unknown. [[26]](#footnote-26)

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The measure life for an induction cooktop is 15 years.[[27]](#footnote-27)

#### Measure Cost

Retrofit:

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

MOP:

* Assume an incremental cost of $300 for replacing standard electric cooktops, and $200 for replacing natural gas or propane cooktops. [[28]](#footnote-28)
* Assume an incremental cost of $247 if the existing cooktop fuel is unknown.[[29]](#footnote-29)

#### 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.

## Building Envelope

### 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 12 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 13

Table 12. Example C/I Air Sealing CO2e Reductions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| CFM50 Reduction | | Fuel | Lifetime CO2e Reductions, Thermal [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
| Range | Assumed Value |
| > 0 and < 800 | 400 | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electricity |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |
| 800 to < 1600 | 1200 | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electricity |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |
| > 1600 | 2000 | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electricity |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Total annual carbon dioxide equivalent emissions reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = CO2e emissions reductions [g] from reducing heating energy

If primary heating fuel is known:

Oil: ΔCO2eheat = ΔEhl / ηave,oil x (CIoil + CI’oil)

Propane: ΔCO2eheat = ΔEhl / ηave,LP x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = (ΔEhl / ηave,NG x CING)/ (1 – TDLNG)

Wood: ΔCO2eheat = ΔEhl / ηave,wood x (CIwood + CI’wood)

Electricity: ΔCO2eheat = (ΔEhl / ηave,elec x CIelec)/ (1 – TDLelec)

If primary heating fuel is unknown:

ΔCO2eheat = (%Oil x ΔEhl x (CIoil+CI’oil)/ηave,oil) + (%LP x ΔEhl x (CILP+CI’LP)) /ηave,LP) + (%NG x ΔEhl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x ΔEhl x CIelec) /ηave,elec)/(1-TDLelec) + (%Wood x ΔEhl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 13) [[30]](#footnote-30)

ηave,oil, etc. = Average heating efficiency for each fuel type [dimensionless] (see Table 13) [[31]](#footnote-31)

Table 13. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

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

ΔEhl = Reduction in heating load [MJ] = [(1.08 x (CFM50pre – CFM50post) / N x Adjheat x HDH)] x 0.00106

Adjheat = Heating adjustment factor to reconcile this simplified algorithm with evaluation bill analysis results = 0.55 [dimensionless].[[32]](#footnote-32)

HDH = Heating degree hours [°F hr] = 113,443.[[33]](#footnote-33)

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool = CO2e reductions [g] from decreased cooling energy = (ΔEcl/ηcool x CIelec)/(1-TDLelec)

ΔEcl = Reduction in cooling load [MJ] = [%Cool x (1.08 x (CFM50pre – CFM50post) / N x Adjcool x CDH)] x 0.00106

%Cool = Percent of Vermont existing buildings with existing cooling. [[34]](#footnote-34)

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

Adjcool = 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].[[35]](#footnote-35)

CDH = Cooling degree hours [°F hr] = 6,619.[[36]](#footnote-36)

ηcool = Cooling system efficiency = 3.52.[[37]](#footnote-37)

ΔCO2efan = CO2e reductions [g] from decreased furnace fan or boiler pump energy = (ΔEfan x CIelec)/(1-TDLelec)

ΔEfan = Reduction in furnace fan or boiler pump energy [MJ]

If heating fuel is known:

ΔEfan = %Fossil x ΔEhl/ηheat x Fe

If heating fuel is unknown:

ΔEfan = %Fossil x (%Oil x ΔEhl/ηave,oil) + (%LP x ΔEhl/ηave,LP) + (%NG x ΔEhl/ηave,NG) + (%Elec x ΔEhl /ηave,elec) + (%Wood x ΔEhl /ηave,wood) x Fe

%Fossil = Percent of Vermont buildings with fossil-fuel furnaces or boilers (from Table 13).

|  |  |
| --- | --- |
| Fossil Fuel System? | %Fossil |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 85% |
| Unknown, Multifamily | 76% |
| Unknown, Building Type Unknown | 84% |

Fe = Furnace/boiler fan/pump energy as a percentage of annual fuel consumption = 3.14%.[[38]](#footnote-38)

**Common Inputs:**

CFM50pre = Pre-installation blower door reading in cubic feet per minute, measured at 50 Pascals pressure differential.

CFM50post = 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].[[39]](#footnote-39)

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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

Lifetime for air sealing is 20 years.[[40]](#footnote-40)

#### Measure Cost

Measure cost of $3,000 per job is assumed for air sealing.[[41]](#footnote-41)

#### 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 (CFM50pre)
* Post-installation blower door measurement at 50 Pascals pressure differential (CFM50post)

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.

### 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 14 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 15

Table 14. Example C/I Building Shell Insulation CO2e Reductions

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Assembly Type | Fuel | R-Value of Insulation Alone | | Lifetime CO2e Reductions, Thermal [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
| Baseline | Proposed |
| Attic,  Standard Wood Framing | Oil | None | R-49 |  |  |  |
| Propane | None | R-49 |  |  |  |
| Natural Gas | None | R-49 |  |  |  |
| Electricity | None | R-49 |  |  |  |
| Wood | None | R-49 |  |  |  |
| Unknown | None | R-49 |  |  |  |
| Exterior Wall, Standard Wood Framing | Oil | None | R-15 |  |  |  |
| Propane | None | R-15 |  |  |  |
| Natural Gas | None | R-15 |  |  |  |
| Electricity | None | R-15 |  |  |  |
| Wood | None | R-15 |  |  |  |
| Unknown | None | R-15 |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Total annual carbon dioxide equivalent emissions reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = CO2e emissions reductions [g] from reducing heating energy

If primary heating fuel is known:

Oil: ΔCO2eheat = ΔEhl / ηave,oil x (CIoil + CI’oil)

Propane: ΔCO2eheat = ΔEhl / ηave,LP x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = (ΔEhl / ηave,NG x CING)/ (1 – TDLNG)

Wood: ΔCO2eheat = ΔEhl / ηave,wood x (CIwood + CI’wood)

Electricity: ΔCO2eheat = (ΔEhl / ηave,elec x CIelec)/ (1 – TDLelec)

If primary heating fuel is unknown:

ΔCO2eheat = (%Oil x ΔEhl x (CIoil+CI’oil)/ηave,oil) + (%LP x ΔEhl x (CILP+CI’LP)) /ηave,LP) + (%NG x ΔEhl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x ΔEhl x CIelec) /ηave,elec)/(1-TDLelec) + (%Wood x ΔEhl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 15) [[42]](#footnote-42)

ηave,fuel = Average heating efficiency for each fuel type [dimensionless] (see Table 15) [[43]](#footnote-43)

Table 15. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

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

ΔEhl**=** Reduction in heating load [MJ] = ((1/Rpre – 1/Rpost) x Ains x HDH x Adjheat) x 0.00106

HDH = Heating degree hours [°F hr], dependent on structure being treated (see below) [[44]](#footnote-44)

| Structure | HDH [°F hr] |
| --- | --- |
| Flat attic or sloped ceiling | 127,961.3 |
| Exterior walls |
| Basement walls | 99,194.6 |

Adjheat = Heating adjustment factor to reconcile this simplified algorithm with evaluation bill analysis results = 0.55 [dimensionless].[[45]](#footnote-45)

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool = CO2e reductions [g] from decreased cooling energy = (ΔEcl/ηcool x CIelec)/(1-TDLelec)

ΔEcl = Reduction in cooling load [MJ] = [%Cool x (1.08 x (CFM50pre – CFM50post) / N x Adjcool x CDH)] x 0.00106

%Cool = Percent of Vermont existing buildings with existing cooling. [[46]](#footnote-46)

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

Adjcool = 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].[[47]](#footnote-47)

CDH = Cooling degree hours [°F hr] = 6,619.[[48]](#footnote-48)

ηcool = Cooling system efficiency = 3.52.[[49]](#footnote-49)

ΔCO2efan = CO2e reductions [g] from decreased furnace fan or boiler pump energy = (ΔEfan x CIelec)/(1-TDLelec)

ΔEfan = Reduction in furnace fan or boiler pump energy [MJ]

If heating fuel is known:

ΔEfan = %Fossil x ΔEhl/ηheat x Fe

If heating fuel is unknown:

ΔEfan = %Fossil x ((%Oil x ΔEhl/ηave,oil) + (%LP x ΔEhl/ηave,LP) + (%NG x ΔEhl/ηave,NG) + (%Elec x ΔEhl /ηave,elec) + (%Wood x ΔEhl /ηave,wood)) x Fe

%Fossil = Percent of Vermont buildings with fossil-fuel furnaces or boilers (from Table 15).

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

Fe = Furnace/boiler fan/pump energy as a percentage of annual fuel consumption = 3.14%.[[50]](#footnote-50)

**Common Inputs:**

Rpre = 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.

Rpost = 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.[[51]](#footnote-51)

Table 16. C/I Insulation: Assembly R-Factors for Attic Roofs with Wood Joists

|  |  |
| --- | --- |
| Rated R-Value of Insulation Alone | Overall R-Factor For Entire Assembly (Rpre, Rpost) |
| 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 17. 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) (Rpre, Rpost) | | | | | | | | | |
| 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 | |
|  |  |  | |  | |  | |  | |  | |  | |  | |  | |
|  |  |  | |  | |  | |  | |  | |  | |  | |  | |
| 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 18. 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 |

Ains = 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### 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.[[52]](#footnote-52)

#### 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. [[53]](#footnote-53)

#### 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 (Ains)
* 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

## Domestic Hot Water

### 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):[[54]](#footnote-54)

Table 19. 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 20 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 21
* Average space heating efficiencies per Table 21
* Tier 1 CHPWH, SysCOP = 1.25
* Small office building, 110 gallons of DHW consumed daily

Table 20. Example C/I Heat Pump Water Heater CO2e Reductions

| Baseline Water Heating Fuel | Proposed Equipment | Space Heating Fuel | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions, Total [g] | | Lifetime Credits | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Oil | CHPWH  Tier 1 | Oil |  | |  | |  |
| Propane |  | |  | |  |
| Natural Gas |  | |  | |  |
| Electricity |  | |  | |  |
| Wood |  | |  | |  |
| Unknown |  | |  | |  |
| Propane | CHPWH  Tier 1 | Oil |  | |  | |  |
| Propane |  | |  | |  |
| Natural Gas |  | |  | |  |
| Electricity |  | |  | |  |
| Wood |  | |  | |  |
| Unknown |  | |  | |  |
| Natural Gas | CHPWH  Tier 1 | Oil |  | |  | |  |
| Propane |  | |  | |  |
| Natural Gas |  | |  | |  |
| Electricity |  | |  | |  |
| Wood |  | |  | |  |
| Unknown |  | |  | |  |
| Unknown | CHPWH  Tier 1 | Oil |  | |  | |  |
| Propane |  | |  | |  |
| Natural Gas |  | |  | |  |
| Electricity |  | |  | |  |
| Wood |  | |  | |  |
| Unknown |  | |  | |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect + ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPWH

CO2ebase = Annual CO2e emissions [g] from baseline water heater

If baseline water heater fuel is known:

Oil: ΔCO2eheat = Qload / EFave.oil x (CIoil + CI’oil)

Propane: ΔCO2eheat = Qload / EFave,LP x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = Qload / EFave,NG x CING / (1 – TDLNG)

If baseline water heater fuel is unknown:

CO2ebase = ((%OilWH x Qload x (CIoil+CI’oil))/EFave) + ((%LPWH x Qload x (CILP+CI’LP)) / EFave) + ((%NGWH x Qload x CING) /EFave)/(1-TDLNG) + ((%ElecWH x Qload x CIelec) /EFave)/(1-TDLelec)

%OilWH, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 21)[[55]](#footnote-55)

EFave,fuel = Average water heater efficiency [dimensionless] by fuel. See Table 21.[[56]](#footnote-56)

Table 21. Vermont Water Heating Fuel Mix and Average Efficiency, C/I Buildings

|  |  |  |
| --- | --- | --- |
| Water Heating Fuel | %FuelWH | Average Efficiency (EFave,fuel) |
| Oil | 11% | 0.77 |
| Propane (LP) | 32% | 0.77 |
| Natural Gas (NG) | 15% | 0.77 |
| Electricity | 42% | 0.94 |

CO2eHPWH = Annual CO2e emissions [g] from heat pump water heater = (Qload / SysCOP x CIelec) / (1 – TDLelec)

SysCOP = NEEA HPWH Cool Climate Efficiency (CCE) rating. Use actual or assume minimum CCE based on tier (see Table 19).

ΔCO2eheat = 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:

Oil: ΔCO2eheat = (ΔEhl / ηave,oil) x (CIoil + CI’oil)

Propane: ΔCO2eheat = (ΔEhl / ηave,LP)x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = (ΔEhl / ηave,NG) x (CING / (1 – TDLNG))

If primary space heating fuel is unknown:

ΔCO2eheat = ((%OilSH x ΔEhl  x (CIoil+CI’oil))/ηave,oil) + ((%LPSH x ΔEhl x (CILP+CI’LP)) /ηave,LP) + ((%NGSH x ΔEhl x CING) /ηave,NG)/(1-TDLNG) + ((%ElecSH x ΔEhl x CIelec) /ηave,elec)/(1-TDLelec) + ((%WoodSH x ΔEhl x (CIwood+ CI’wood)) /ηave,wood)

%OilSH, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 22)[[57]](#footnote-57)

ηave,oil, etc. = Average heating efficiency for each fuel type [dimensionless] (see Table 22)[[58]](#footnote-58)

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

|  |  |  |
| --- | --- | --- |
| Space Heating Fuel | %Fuelsh | Average Space Heating Efficiency (ηave,fuel) |
| Oil | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural Gas | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

ΔEhl = Space heating load change = −(Qload x IFheat) / CCEHPWH

IFheat = Interactive factor, portion of HPWH ambient cooling impact that results in increased space heating = 0.542.[[59]](#footnote-59)

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool  = Space cooling impacts [g] = (ΔEcl x CIelec) /ηcool / (1 – TDLelec)

ηcool = Assumed cooling system COP = 3.52.[[60]](#footnote-60)

ΔEcl = Change in cooling load [MJ] = (Qload x IFcool) / CCEHPWH

IFcool = Interactive factor, portion of HPWH ambient cooling impact that results in decreased space cooling = 0.188 [[61]](#footnote-61)

%Cool = Percent of Vermont C/I facilities with cooling[[62]](#footnote-62)

Table 23. Percentage of C/I Customers with Cooling

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

**Common Inputs**

Qload = Annual water heating load [MJ] = (8.33 x (Tset – Tinlet) x GPD/unit x 365) x 0.00106

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

Tset = Hot water temperature setpoint [°F]. From application or assume 140°F.[[63]](#footnote-63)

Tinlet = Inlet water temperature of water entering the facility = 51.8°F.[[64]](#footnote-64)

GPD/unit = Average gallons per day of domestic hot water delivered by baseline water heater over one year. From application or estimate from Table 24[[65]](#footnote-65) 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 24. 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[[66]](#footnote-66): 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[[67]](#footnote-67): School with Showers |
| Dormitory | 8600 | 17.2 GPD per resident | Assumes 500 residents | Water Research Foundation[[68]](#footnote-68) |
| Elementary School | 250 | 0.5 GPD per student | Assumes 500 students | NREL: School |
| Fast Food Restaurant | 500 | 500 GPD per restaurant |  | FSTC[[69]](#footnote-69): 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[[70]](#footnote-70) |
| 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 | Cal-culate | 4.89 GPD per 1,000 SF | Assumes 10% hot water | EIA: Other |

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 12 years.[[71]](#footnote-71)

#### 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:

* 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.

### 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, 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.[[72]](#footnote-72)

New Construction: New standard flow rate faucet aerator rated at 1.5 GPM.[[73]](#footnote-73)

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.

New Construction:Faucet aerator rated at 1.3 GPM [[74]](#footnote-74)

#### 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 25 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 26
* Water heater efficiencies per Table 26
* Unknown building type

Table 25. Example Lifetime Faucet Aerator CO2e Reductions

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Program Delivery Type | Faucet Type | Baseline Aerator | Proposed Aerator | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions,  Total [g] | Lifetime Credits |
| Direct Install | Kitchen | 2.2 GPM | 1.5 GPM |  |  |  |
| Bath | 2.2 GPM | 1.0 GPM |  |  |  |
| New Construction | Kitchen | 1.5 GPM | 1.3 GPM |  |  |  |
| Bath | 1.5 GPM | 1.3 GPM |  |  |  |
| Free Products | Kitchen | 2.2 GPM | 1.5 GPM |  |  |  |
| Bath | 2.2 GPM | 1.0 GPM |  |  |  |
| Dropship | Kitchen | 2.2 GPM | 1.5 GPM |  |  |  |
| Bath | 2.2 GPM | 1.0 GPM |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector Decarbonization Impacts:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement

If water heater fuel is known:

Oil: ΔCO2edirect = (ΔEwhl x (CIoil + CI’oil)) / REoil

Propane: ΔCO2edirect = (ΔEwhl x (CIoil + CI’oil)) / RELP

Natural Gas: ΔCO2edirect = ((ΔEwhl x CING) / RENG) / (1 – TDLNG)

Electricity: ΔCO2edirect = ((ΔEwhl x CIelec) / REelec) / (1 – TDLelec)

If water heater fuel is unknown:

ΔCO2e = (%Oil x ΔEwhl x (CIoil + CIoil))/REoil + (%LP x ΔEwhl x (CILP + CI’LP)) / RELP + (%NG x ΔEwhl x CING)/ RENG)/(1-TDLNG) + (%Elec x ΔEwhl x CIelec)/ REelec)/(1-TDLelec)

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 26)[[75]](#footnote-75)

REoil etc. = Average water heater recovery efficiency by fuel type (see

Table 26)[[76]](#footnote-76)

Table 26. Vermont Water Heating Fuel Mix and Average Recovery Efficiency, C/I Buildings

|  |  |  |
| --- | --- | --- |
| Water Heating Fuel | %Fuel | Recovery Efficiency (REfuel) |
|
| Oil | 11% | 0.83 |
| Propane (LP) | 32% | 0.83 |
| Natural Gas | 15% | 0.83 |
| Electricity | 42% | 1.71 |

ΔEwhl = Reduction in water heating load [MJ] = (GPMBase x ThrottleBase – GPMLow x ThrottleLow) x 60 x (Hrs/Day) x (Days/Year) x 8.3 x (TFaucet – Tinlet) x ISR x 0.00106

GPMBase = Flow rate of existing faucet aerator = 2.2 GPM for retrofit; 1.5 GPM for new construction

GPMLow = 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

= 1.5 GPM for free products

Throttle­Base = Percentage of full-throttle flow rate for baseline faucet = 83% [[77]](#footnote-77)

ThrottleLow = Percentage of full-throttle flow rate for low flow faucet = 95% [[78]](#footnote-78)

Hours/Day = Hours per day the faucet is used = 0.25 [[79]](#footnote-79)

Days/Year = Operating days per year, based on facility type.[[80]](#footnote-80)

Table 27. 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[[81]](#footnote-81) | 302 |

TFaucet = Mixed water temperature (°F) of hot water coming from faucet = 86°F (bathroom); 93°F (kitchen)[[82]](#footnote-82)

Tinlet = Inlet water temperature (°F) of water entering the household = 51.8°F[[83]](#footnote-83)

ISR = In-service rate, the percentage of incentivized units actually installed [[84]](#footnote-84)

Table 28. 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs:**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life of installed equipment is estimated to be 10 years.[[85]](#footnote-85)

#### 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.[[86]](#footnote-86)

#### 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 (GPMLow)
* Water heater fuel
* Building type

Free Giveaways:

* Aerator flow: 1.0, 1.3, or 1.5 GPM (GPMLow)

#### Energy Codes and Standards

The baseline assumption for new construction is assumed to be the state standard which took effect on 7/1/2020[[87]](#footnote-87).

* + - 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.

### 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, 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.[[88]](#footnote-88)

New Construction: New standard flow rate showerhead rated at 2.0 GPM. [[89]](#footnote-89)

**Proposed Conditions**

Direct Install and Dropship: Low flow showerhead rated at 1.5 GPM. [[90]](#footnote-90)

New Construction: Showerhead rated at 1.8 GPM. [[91]](#footnote-91)

#### 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>).Decarbonization Summary

Table 29 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 30
    - Water heater efficiencies per Table 30
    - One shower taken per day for 365 days per year (example only, not a deemed parameter)

Table 29. Example C/I Low Flow Showerhead CO2e Reductions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Program Delivery Type | Baseline Showerhead | Proposed Showerhead | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions,  Total [g] | Lifetime Credits |
| Direct Install | 2.5 GPM | 1.5 GPM |  |  |  |
| New Construction | 2.0 GPM | 1.8 GPM |  |  |  |
| Free Products | 2.5 GPM | 1.5 GPM |  |  |  |
| Dropship | 2.5 GPM | 1.5 GPM |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement

If water heater fuel is known:

Oil: ΔCO2edirect = (ΔEwhl x (CIoil + CI’oil)) / REoil

Propane: ΔCO2edirect = (ΔEwhl x (CIoil + CI’oil)) / RELP

Natural Gas: ΔCO2edirect = ((ΔEwhl x CING) / RENG) / (1 – TDLNG)

Electricity: ΔCO2edirect = ((ΔEwhl x CIelec) / REelec) / (1 – TDLelec)

If water heater fuel is unknown:

ΔCO2e = (%Oil x ΔEwhl x (CIoil + CIoil))/REoil + (%LP x ΔEwhl x (CILP + CI’LP)) / RELP + (%NG x ΔEwhl x CING)/ RENG)/(1-TDLNG) + (%Elec x ΔEwhl x CIelec)/ REelec)/(1-TDLelec)

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 33)[[92]](#footnote-92)

REoil etc. = Average water heater recovery efficiency by fuel type (see

Table 26)[[93]](#footnote-93)

Table 30. Vermont Water Heating Fuel Mix and Average Recovery Efficiency, C/I Buildings

|  |  |  |
| --- | --- | --- |
| Water Heating Fuel | %Fuel | Recovery Efficiency (REfuel) |
|
| Oil | 11% | 0.83 |
| Propane (LP) | 32% | 0.83 |
| Natural Gas | 15% | 0.83 |
| Electricity | 42% | 1.71 |

ΔEwhl = Reduction in water heating load [MJ]

= ((GPMBase - GPMLow) x (Minutes/Use) x (Uses/Day) x (Days/Year) / 8.3 x (TSh – Tinlet) / ηRE x ISR x 0.00106

GPMBase = Flow rate of existing showerhead = 2.5 GPM for Retrofits, 2.0 GPM for New Construction.

GPMLow = 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 = 7.8 [[94]](#footnote-94)

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

TSh = Mixed water temperature (°F) of hot water coming from showerhead = 101°F [[95]](#footnote-95)

Tinlet = Inlet water temperature (°F) of water entering the building= 51.8°F [[96]](#footnote-96)

ISR = In-service rate, the percentage of incentivized units actually installed [[97]](#footnote-97)

Table 31. 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life of installed equipment is estimated to be 10 years. [[98]](#footnote-98)

#### 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.[[99]](#footnote-99)

#### 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 (GPMLow)
* Water heater fuel
* Number of showers per day per showerhead

#### Energy Codes and Standards

The baseline assumption for new construction is assumed to be the state standard which took effect on 7/1/2020[[100]](#footnote-100).

* + - 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.

### 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).[[101]](#footnote-101)

#### Decarbonization Summary

Table 32 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:

* Baseline and backup water heater fuels are the same
* Baseline water heater efficiency by fuel per Table 33

Table 32. Example C/I Solar Water Heater CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| Backup Fuel | SUEF Range | Assumed SUEF | Lifetime CO2e reductions [g] |
| Oil | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |
| Natural Gas | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |
| Propane | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |
| Electricity | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |
| Unknown | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 clean heat credit per metric ton of CO2e reductions.

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eswh

CO2ebase = Annual CO2e emissions [g] from baseline water heater

If baseline water heater fuel is known:

Oil: CO2ebase = (Qload x (CIoil+CI’oil)/EFmin)

Propane: CO2ebase = (Qload x (CILP+CI’LP)/EFmin

Natural Gas: CO2ebase = (Qload / EFmin) / (1 – TDLNG)

Electricity: CO2ebase = (Qload / EFmin) / (1 – TDLelec)

If baseline water heater fuel is unknown:

CO2ebase = ((%OilWH x Qload x (CIoil+CI’oil))/EFmin) + ((%LPWH x Qload x (CILP+CI’LP)) /EFmin) + ((%NGWH x Qload x CING) /EFmin)/(1-TDLNG) + ((%ElecWH x Qload x CIelec) /EFmin)/(1-TDLelec)

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 33)[[102]](#footnote-102)

EFmin = Minimum water heater efficiency [dimensionless] by fuel. Based on CFR minimum efficiency requirements for commercial water heating equipment. See Table 33.[[103]](#footnote-103)

Table 33. Vermont Water Heating Fuel Mix and Minimum Heating Efficiency, C/I Buildings

|  |  |  |
| --- | --- | --- |
| Water Heating Fuel | %Fuelwh | Minimum Water Heater Efficiency (EFmin) |
| Oil | 11% | 0.80 |
| Propane (LP) | 32% |
| Natural Gas (NG) | 15% |
| Electricity | 42% |

CO2eswh = Annual CO2e emissions [g] from solar water heater

If backup water heater fuel is known:

Oil: CO2eswh = (Qload x (CIoil+CI’oil)/SUEF)

Propane: CO2eswh = (Qload x (CILP+CI’LP)/SUEF

Natural Gas: CO2eswh = (Qload / SUEF x CING) / (1 – TDLNG)

Electricity: CO2eswh = (Qload / SUEF x CIelec) / (1 – TDLelec)

If backup water heater fuel is unknown:

CO2eSWH = ((%Oil x Qload x (CIoil+CI’oil))/SUEF) + ((%LP x Qload x (CILP+CI’LP)) /SUEF) + ((%NG x Qload x CING) /SUEF)/(1-TDLNG) + ((%Elec x Qload x CIelec) /SUEF)/(1-TDLelec)

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**

Qload = Annual water heating load [MJ] = (8.33 x (Tset – Tinlet) x GPD/unit x 365) x 0.00106

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

Tset = Hot water temperature setpoint [°F]. From application or assume 140°F.[[104]](#footnote-104)

Tinlet = Inlet water temperature of water entering the facility = 51.8°F.[[105]](#footnote-105)

GPD/unit = Average gallons per day of domestic hot water delivered by baseline water heater over one year. From application or estimate from Table 34 using rate if facility size in square feet (SF) is known, or use default GPD.[[106]](#footnote-106) 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 34. 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[[107]](#footnote-107): 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[[108]](#footnote-108): School with Showers |
| Dormitory | 8600 | 17.2 GPD per resident | Assumes 500 residents | Water Research Foundation[[109]](#footnote-109) |
| Elementary School | 250 | 0.5 GPD per student | Assumes 500 students | NREL: School |
| Fast Food Restaurant | 500 | 500 GPD per restaurant |  | FSTC[[110]](#footnote-110): 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[[111]](#footnote-111) |
| 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 | Cal-culate | 4.89 GPD per 1,000 SF | Assumes 10% hot water | EIA: Other |

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

20 years[[112]](#footnote-112)

#### Measure Cost

* Retrofit: Use actual installed cost of SWH if available, or assume $6,000 for planning purposes.[[113]](#footnote-113)
* MOP: Determine incremental cost of SWH compared to a conventional gas or electric storage water heater. Default value is $4,731.[[114]](#footnote-114)

#### 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.

## HVAC

### 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, 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.[[115]](#footnote-115)

**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 communication and exceed the typical performance of manual and conventional programmable thermostats through the automatic or default capabilities described above.[[116]](#footnote-116)

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 35 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 38):
  + - Retrofit: 53,277 Btu/h
    - New Construction: 33,427

Table 35. Example C/I Advanced Thermostat Lifetime CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Decision/Action Type | Heating Fuel | Lifetime CO2e Reductions, Thermal [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
| Retrofit | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electricity |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |
| New Construction | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electricity |  |  |  |
| Unknown |  |  |  |
| Wood |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Total annual carbon dioxide equivalent emissions reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = CO2e emissions reductions from reducing heating energy

If heating fuel is known:

Oil: ΔCO2eheat = ΔEheat x (CIoil + CI’oil)

Propane: ΔCO2eheat = ΔEheat x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = (ΔEheat x CING)/ (1 – TDLNG)

Wood: ΔCO2eheat = ΔEheat x (CIwood + CI’wood)

Electricity: ΔCO2eheat = (ΔEheat x CING)/ (1 – TDLelec)

If heating fuel is unknown:

ΔCO2eheat = (%Oil x ΔEheat x (CIoil+CI’oil)) + (%LP x ΔEheat x (CILP+CI’LP)) + (%NG x ΔEheat x CING)/(1-TDLNG) + (%Elec x ΔEheat x CIelec)/(1-TDLelec) + (%Wood x ΔEheat x (CIwood+ CI’wood))

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 36)[[117]](#footnote-117)

Table 36. Vermont Primary Heating Fuel Mix, C/I Buildings

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

ΔEheat = Heating energy reduction [MJ] = (EFLHheat × Btuhin,heat x SFheat x (1 - %CHP)) x 0.00106

EFLHheat = Annual equivalent full load heating hours for heating equipment

Table 37. Equivalent Full Load Hours, Heating

| Decision/Action Type | EFLHheat [[118]](#footnote-118) |
| --- | --- |
| Retrofit | 1062 |
| New Construction | 1062 |

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

For fossil fuel system, use rated if known, or defaults in Table 38.

For heat pump system, Btuhin,heat =Btuhout,heat / COPheat where Btuhout,heat = rated heating output capacity at 47°F in Btu/h. Use rated output capacity if known, or defaults in Table 39. COPheat = Heating coefficient of performance (COP) of heat pump = 3.28.[[119]](#footnote-119)

For wood heater, use defaults in Table 38 or calculate from rated capacity: Btuhin,heat =Btuhout,heat / ηw where ηw = wood heating efficiency. Assume ηw = 65% if unknown.[[120]](#footnote-120)

Table 38. Input Capacity of Fossil Heating System

| Decision / Action Type | BTUhin,heat [[121]](#footnote-121) |
| --- | --- |
| Early Replacement | 53,277 |
| New Construction | 33,427 |

Table 39. Heating Output Capacity of Heat Pump System

| Decision / Action Type | Btuhout,heat [[122]](#footnote-122) |
| --- | --- |
| Early Replacement | 53,186 |
| New Construction | 31,683 |

SFheat = Assumed savings factor for total heating energy consumption due to installation of advanced thermostat. See Table 42.

%CHP= Percentage of customers with central air source or ground source heat pumps as the primary heating system. This variable is used to account for heat pump manufacturer recommendations to limit temperature setbacks during the heating season. [[123]](#footnote-123)

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

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool = (ΔEcool x CIelec ) / (1 - TDLelec)

ΔEcool = Cooling energy reduction [MJ] = %Cool x (EFLHcool × Btuhout,cool / COPcool × SFcool) × 0.00106

Btuhout,cool = Output cooling capacity of heat pump or AC [Btu/h] = 41,400 [[124]](#footnote-124)

%Cool = Percentage of customers with central cooling systems[[125]](#footnote-125)

Table 40. Percentage of C/I Customers with Cooling

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

EFLHcool = Estimate of annual equivalent full load cooling hours for heat pump or air conditioner = 375.[[126]](#footnote-126)

COPcool = Cooling coefficient of performance for air-conditioner or heat pump

Table 41. Cooling COP

| Decision/Action Type | COPcool |
| --- | --- |
| Early Replacement[[127]](#footnote-127) | 4.10 |
| New Construction[[128]](#footnote-128) | 5.04 |

SFcool = 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 42.

**Common Inputs**

Table 42. Advanced Thermostat Savings Factors

| Decision / Action Type | Heating Savings Factor[[129]](#footnote-129) | Cooling Savings Factor[[130]](#footnote-130) |
| --- | --- | --- |
| Early Replacement | 8.0% | 8.0% |
| New Construction | 5.6% | 8.0% |

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

0.00106 = MJ per BTU.

#### Measure Life

The expected measure life of installed equipment is estimated to be 10 years. [[131]](#footnote-131)

#### 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. [[132]](#footnote-132)

#### 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.

### 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:** Thermal Efficiency

**Applicable Baseline Fuels:** Wood Pellets

**Decision/Action Type:** MOP, 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 new or existing C/I buildings. 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).

This characterization describes the carbon reductions achieved by replacing a low efficiency central wood heating system with an efficient central wood heating system. Refer to the Wood Heating fuel measure characterizations for the carbon reductions associated with switching from fossil fuel heating to wood heating.

**Baseline Conditions**

MOP: The baseline is assumed to be a new central pellet system with a full load efficiency of 75% HHV.

Retrofit: The baseline is assumed to be an existing wood heating system with a full load efficiency of 65% HHV.

**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 ≥ 85% (HHV) as certified by EPA
* PM2.5 emissions rate < 0.08 lbs/MMBTU as certified by EPA
* Is the primary heating system for the zone(s) it serves

#### Decarbonization Summary

Table 43 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:

* Proposed system efficiency is 86% HHV at full load
* Wood pellets only
* Baseline efficiencies
  + - MOP: 75% HHV at full load
    - Retrofit: 65% HHV at full load
* Efficient pellet system meets 90% of the annual heating load for Retrofits, and 100% for MOP

Table 43. Example C/I Advanced Wood Heating CO2e Reductions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Decision/  Action Type | Capacity Range  [Btu/h] | Assumed Capacity  [Btu/h] | Lifetime CO2e reductions [g],  Thermal Sector | Lifetime CO2e reductions [g],  Total | Lifetime Credits |
| MOP | 25,000 - 80,000 | 55,000 |  |  |  |
| 80,001 - 150,000 | 101,000 |  |  |  |
| 150,001 - 340,000 | 207,000 |  |  |  |
| Retrofit | 25,000 - 80,000 | 55,000 |  |  |  |
| 80,001 - 150,000 | 101,000 |  |  |  |
| 150,001 - 340,000 | 207,000 |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = Annual CO2e reductions [g] due to more efficient wood pellet system

= ΔEheat x (CIpellet + CI’wood)

ΔEheat = Energy savings from upgrading to efficient wood pellet system in megajoules [MJ]

= (%Pellet x Btuh x EFLH x (1/ηbase – 1/ηeff)) x 0.00106

%Pellet = Percentage of annual heating load provided by pellet system[[133]](#footnote-133)

|  |  |
| --- | --- |
| Decision/Action Type | %Pellet |
| MOP[[134]](#footnote-134) | 100% |
| Retrofit[[135]](#footnote-135) | 90% |

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

EFLH = Heating equivalent full load hours = 1,062 [[136]](#footnote-136)

ηbase = Baseline pellet system efficiency

|  |  |
| --- | --- |
| Decision/Action Type | ηbase |
| MOP[[137]](#footnote-137) | 75% |
| Retrofit[[138]](#footnote-138) | 65% |

ηeff = Efficient pellet system efficiency = 86%.[[139]](#footnote-139)

0.00106 = MJ per BTU.

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is 18 years.[[140]](#footnote-140)

#### Measure Cost

|  |  |  |
| --- | --- | --- |
| Decision/Action Type | Cost Type | Cost |
| MOP[[141]](#footnote-141) | Incremental | $11,764 |
| Retrofit[[142]](#footnote-142) | 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 (ηeff)

#### Energy Codes and Standards

All new wood heating appliances offered for sale in the US are required to meet New Source Performance Standards (NSPS)[[143]](#footnote-143) 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>).

### Advanced Wood Heating – Pellet and Cordwood Stoves

**CHS Measure ID:** CI\_HVAC\_AWHS

**Market Sector:** Commercial/Industrial

**End Use:** HVAC

**Applicable Building Types:** Non-Residential, Multifamily Common Areas

**Decarbonization Pathways:** Thermal Efficiency

**Applicable Baseline Fuels:** Wood Pellets, Firewood

**Decision/Action Type:** Retrofit

**Program Delivery Type:** Downstream

#### Measure Description

This measure involves the installation of advanced pellet and firewood stoves in existing C/I buildings to replace older, less efficient wood-burning stoves. 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 PM2.5 emissions rates of at least 70% and no more than 2.0 g/hr, respectively. (PM2.5 refers to “fine particles” having an aerodynamic diameter of 2.5 microns or less.)

This characterization describes the carbon reductions achieved by replacing a low efficiency wood-burning stove with an efficient pellet or firewood stove. Refer to the Wood Heating fuel measure characterizations for the carbon reductions associated with switching from fossil fuel heating to wood heating.

**Baseline Conditions**

The baseline is assumed to be an existing, less efficient wood stove supplementing an existing heating system.

**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 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%
* PM2.5 ≤ 2.0 g/hr

#### 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 stove is 76%
* Existing stove efficiency is 52%
* Primary heating system capacity = 90,000 Btu/h

Table 44. Example C/I Efficient Wood Stove CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| New Stove Type | Lifetime CO2e reductions [g],  Thermal Sector | Lifetime CO2e reductions [g],  Total | Lifetime Credits |
| Pellet |  |  |  |
| Cordwood |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = Annual CO2e reductions [g] due to more efficient wood stove

For pellet stoves:

ΔCO2eheat = (Ehl x (CIfirewood + CI’wood))/ηbase – (Ehl x (CIpellet + CI’wood))/ηeff,pellet

For cordwood stoves:

ΔCO2eheat = (Ehl x (CIfirewood + CI’wood))/ηbase – (Ehl x (CIfirewood + CI’wood))/ηeff,cordwood

Ehl = Wood stove heating load in megajoules [MJ] = (%Stove x Capacity x EFLH) x 0.00106

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

|  |  |
| --- | --- |
| Stove Type | %Stove |
| Pellet[[144]](#footnote-144) | 64% |
| Cordwood[[145]](#footnote-145) | 65% |

Capacity = Average capacity of primary space heating system.

EFLH = Heating equivalent full load hours for stove = 1,400.[[146]](#footnote-146)

ηbase = Existing stove efficiency = 52%.[[147]](#footnote-147)

ηeff = Certified efficiency of new stove. Use actual or assume defaults below.[[148]](#footnote-148)

|  |  |
| --- | --- |
| Stove Type | Efficiency (ηeff) |
| Pellet | 77% |
| Cordwood | 75% |

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

CI = Carbon intensity of fuel [g CO2e/MJ]. See Table x in Reference Section.

CI’ = Carbon intensity adder for delivery of fuel to end user. See Table z in Reference Section.

#### Measure Life

The expected measure life is 18 years.[[149]](#footnote-149)

#### 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 |
| Cordwood | $2,475 | $383 | $469 | $3,319 |

\*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 (ηeff)

#### Energy Codes and Standards

All new wood heating appliances offered for sale in the US are required to meet New Source Performance Standards (NSPS)[[150]](#footnote-150) 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.[[151]](#footnote-151)

### Air Source Heat Pump – Full Displacement

**CHS Measure ID:** CI\_HVAC\_HPDF

**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 ≥ 14.3, HSPF2 ≥ 7.7
  + Non-Ducted: SEER2 ≥ 15, HSPF2 ≥ 7.5
  + COP at 5°F ≥ 1.75 at maximum capacity operation)[[152]](#footnote-152)
* 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 45 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 45. Example C/I ASHP-Full Displacement CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Heat Pump Type | Baseline Heating Fuel | Lifetime CO2e Reductions per TonR [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR [g CO2e/tonR],  Total | Lifetime Credits per TonR |
| Ducted | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Non-Ducted | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 46) [[153]](#footnote-153)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 46)[[154]](#footnote-154)

Table 46. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

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

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / HSPF2 x 3.412) x CIelec / (1 – TDLelec)

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh] = 7.7 (Ducted), 7.5 (Non-Ducted).

3.412 = Btu per Watt-hour. Used to convert HSPF2 [Btu/(Watt hour)] to COP [dimensionless). COP = HSPF2/3.412.

Ehl = Heating load served by the heat pump [MJ] = (HCAP47F x EFLHheat) x 0.00106

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,681 hours. [[155]](#footnote-155)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/SEER2) x 0.0036

%Cool = Percent of Vermont facilities with existing cooling. [[156]](#footnote-156)

|  |  |
| --- | --- |
| 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).

EFLHcool = Equivalent full load cooling hours = 591 hours. [[157]](#footnote-157)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 16 years.[[158]](#footnote-158)

#### Measure Cost

The assumed full retrofit cost of air source heat pumps is below:

| Capacity (Btu/h) | Ducted[[159]](#footnote-159) | Non-Ducted, Single Head[[160]](#footnote-160) | Non-Ducted, Multi- Head[[161]](#footnote-161) |
| --- | --- | --- | --- |
| 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 (HCAP47F).
* 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.

### 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:

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 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 ≥ 7.2[[162]](#footnote-162)
* 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 47 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 47. Example C/I ASHP-Partial Displacement CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Heat Pump Type | Baseline Heating Fuel | Lifetime CO2e Reductions per TonR [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Split System | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Single Package | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 48) [[163]](#footnote-163)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 48)[[164]](#footnote-164)

Table 48. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

|  |  |  |
| --- | --- | --- |
| Heating Fuel | C/I Sector % | Average Heating Efficiency (ηave) |
| Oil | 15% | 0.81 |
| Propane (LP) | 29% | 0.88 |
| Natural Gas (NG) | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / HSPF2 x 3.412) x CIelec / (1 – TDLelec)

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh] = 7.8 (Split System), 7.2 (Single Package).

3.412 = Btu per Watt-hour. Used to convert HSPF2 [Btu/(Watt hour)] to COP [dimensionless). COP = HSPF2/3.412.

Ehl = Heating load served by the heat pump [MJ] = (HF x HCAP47F x EFLHheat) x 0.00106

HF = Heatload Factor, reduces EFLH to account for partial displacement.= 31%.[[165]](#footnote-165)

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,681 hours. [[166]](#footnote-166)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/SEER2) x 0.0036

%Cool = Percent of Vermont facilities with central cooling. [[167]](#footnote-167)

|  |  |
| --- | --- |
| 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)

EFLHcool = Equivalent full load cooling hours = 591 hours. [[168]](#footnote-168)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 16 years.[[169]](#footnote-169)

#### Measure Cost

The assumed full retrofit cost of air source heat pumps is below:

| Capacity (Btu/h) | Ducted[[170]](#footnote-170) | Non-Ducted, Single Head[[171]](#footnote-171) | Non-Ducted, Multi- Head[[172]](#footnote-172) |
| --- | --- | --- | --- |
| 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 (HCAP47F).
* 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

ENERGY STAR Product Specification for Central Air Conditioner and Heat Pump Equipment, Version 6.1.

### 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 49 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 COPheat = 2.83
* Existing A/C system presence is unknown

Table 49. Example C/I AWHP CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| Existing Heating Fuel | Lifetime CO2e Reductions per TonR  [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR  [g CO2e/tonR], Total | Lifetime Credits  per TonR |
| Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 50) [[173]](#footnote-173)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 50)[[174]](#footnote-174)

Table 50. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

|  |  |  |
| --- | --- | --- |
| Heating Fuel | Fuel % | Average Heating Efficiency (ηave,fuel) |
| Oil | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural Gas | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

CO2eHPheat = Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / COPhp) x CIelec / (1 – TDLelec)

COPhp = Coefficient of Performance (COP) rating for heat pump (heating efficiency) [dimensionless]. Use average COP over operating conditions or refer to Table 51 if unknown.

Ehl = Heating load served by the heat pump [MJ] = (HCAP47F x EFLHheat) x 0.00106

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,681 hours.[[175]](#footnote-175)

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =ΔCO2e emissions due to added cooling load = (ΔEcool x CIelec) / (1-TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/COPhp) x 0.00106

%Cool = Percent of Vermont facilities with existing cooling. [[176]](#footnote-176)

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

CCAP = Rated cooling output capacity of heat pump in Btu’s per hour [Btu/h]

EFLHcool = Equivalent full load cooling hours = 591 hours.[[177]](#footnote-177)

**Common Inputs**

Table 51. Default AWHP Efficiency

| Rated Heating Capacity [tonsR] | COPhp[[178]](#footnote-178) |
| --- | --- |
| 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

0.00106 = MJ per Btu.

#### Measure Life

The expected measure life is assumed to be comparable to an air-to-air heat pump: 16 years.[[179]](#footnote-179)

#### 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.[[180]](#footnote-180) 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] | [[181]](#footnote-181)Retrofit Cost[[182]](#footnote-182) |
| 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

### 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:[[183]](#footnote-183)

Table 52. 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 53 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 53. Example C/I GSHP Lifetime CO2e Reductions per TonR

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| GSHP Type | Baseline Heating Fuel | Lifetime CO2e Reductions per TonR  [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR  [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Water-to-Air, Closed Loop | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Water-to-Air, Open Loop | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Water-to-Water, Closed Loop | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Water-to-Water, Open Loop | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| DGX-to-Air | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| DGX-to-Water | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 54) [[184]](#footnote-184)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 54) [[185]](#footnote-185)

Table 54. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

| Heating Fuel | Fuel % | Average Heating Efficiency (ηheat) |
| --- | --- | --- |
| Oil | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural Gas | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / COP) x CIelec / (1 – TDLelec)

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 52).

Ehl = Heating load served by the heat pump [MJ] = (HCAP x EFLHheat) x 0.00106

HCAP47F = Rated heating output capacity of heat pump in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,681 hours.[[186]](#footnote-186)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/EER) x 0.0036

%Cool = Percent of Vermont existing buildings with cooling.[[187]](#footnote-187)

|  |  |
| --- | --- |
| Central Cooling? | %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 52).

EFLHcool = Equivalent full load cooling hours = 591 hours. [[188]](#footnote-188)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### 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.[[189]](#footnote-189)

#### 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.[[190]](#footnote-190)

#### 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

#### Energy Codes and Standards

ENERGY STAR® Program Requirements Product Specification for Geothermal Heat Pumps: Eligibility Criteria Version 3.2.

### 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.[[191]](#footnote-191) 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°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 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:[[192]](#footnote-192)

Table 55. 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 56 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 55)
* Existing A/C presence is unknown

Table 56. Example VRF Lifetime CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| Existing Heating Fuel | Lifetime CO2e Reductions per TonR  [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR  [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 57)[[193]](#footnote-193)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 57)[[194]](#footnote-194)

Table 57. Vermont Heating Fuel Mix and Average Heating Efficiency, C/I Buildings

|  |  |  |
| --- | --- | --- |
| Heating Fuel | %Fuel | Average Heating Efficiency  (ηave,fuel) |
| Oil | 15% | 0.81 |
| Propane | 29% | 0.88 |
| Natural Gas | 22% | 0.88 |
| Electricity | 33% | 3.66 |
| Wood | 1% | 0.75 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / COP47F) x CIelec / (1 – TDLelec)

COP47F = 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 55

Ehl = Heating load served by the heat pump [MJ] = (HCAP47F x EFLHheat) x 0.00106

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,681 hours.[[195]](#footnote-195)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/IEER) x 0.0036

%Cool = Percent of Vermont facilities with existing cooling.[[196]](#footnote-196)

|  |  |
| --- | --- |
| 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 55.

EFLHcool = Equivalent full load cooling hours = 591 hours.[[197]](#footnote-197)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 16 years.[[198]](#footnote-198)

#### 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 (HCAP47F).
* 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 (COP47F)
* 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).

## Miscellaneous

### 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 58 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 33
* Heat pump pool water heater COP = 4.79
* Pool kept at 82°F from June 1 through September 30
* Pool cover use unknown

Table 58. Example C/I Heat Pump Pool Water Heater CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| Baseline Fuel | Lifetime CO2e reductions per SF [g/ft2], Thermal Sector | Lifetime CO2e reductions per SF [g/ft2], Total | Lifetime Credits per SF |
| Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase - CO2eHP

CO2ebase = Annual CO2e emissions [g] from baseline pool water heater

Oil: CO2ebase = Eload / ηave,oil x (CIoil + CI’oil)

Propane: CO2ebase = Eload / ηave,LP x (CILP + CI’LP)

Natural Gas: CO2ebase = (Eload / ηave,NG x CING) / (1 – TDLNG)

ηave,fuel = Assumed average pool water heater efficiency by fuel (see Table 59)[[199]](#footnote-199)

Table 59. Vermont Pool Water Heating Efficiency, C/I Buildings

|  |  |
| --- | --- |
| Pool Water Heating Fuel | Average Efficiency (ηave,fuel) |
| Oil | 0.85 |
| Propane (LP) | 0.85 |
| Natural Gas | 0.85 |
| Electricity | 0.99 |

CO2eHP = CO2e emissions from heat pump pool water heater [g] = (Eload / COPHP x CIelec) / (1 – TDLelec)

COPHP = Coefficient of performance (COP) of proposed heat pump pool water heater [dimensionless]. Use actual or assume 4.79 if unknown.[[200]](#footnote-200)

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

Eload = Annual pool water heating load [MJ] =

= (((BTUperSFsurface + BTUperSFevap - BTUperSFsolar) x Awater) + (BTUperGalreheat x Vwater)) x 0.00106

Awater = Surface area of water in square feet [ft2], from application.

Vwater = Pool water capacity in gallons [gal], from application

BTUperSFsurface = 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 Btu/ft2 (no pool cover)

= 217,871 Btu/ft2 (pool covered from 8pm to 8am)

= 240,458 Btu/ft2 (pool cover use unknown)[[201]](#footnote-201)

BTUperGalreheat = 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°F[[202]](#footnote-202) to 82°F.

= 250 Btu/gal

BTUperSFevap = 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 Btu/ft2 (no pool cover)

= 3,294 Btu/ft2 (pool covered from 8pm to 8am)

= 3,303 Btu/ft2 (pool cover use unknown)

BTUperSFsolar = 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.[[203]](#footnote-203)

= 88,086 Btu/ft2 (with or without pool cover)

COPHP = Coefficient of performance (COP) of proposed heat pump pool water heater [dimensionless]. Use actual or assume 4.79 if unknown. [[204]](#footnote-204)

0.00106 = MJ per BTU

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 5 years.[[205]](#footnote-205)

#### Measure Cost

The retrofit cost of a heat pump pool water heater is $4,200.[[206]](#footnote-206)

#### Program Data Tracking Recommendations

The following variables should be tracked for this measure:

* Fuel type and efficiency of existing pool heater (ηbase)
* COP of proposed heat pump water heater (COPhp)
* Use of pool cover and estimated hours of use
* Surface area of pool water in square feet (Awater)
* Full volume of pool water in gallons (Vwater)

#### Energy Codes and Standards

Minimum efficiencies for pool heaters are prescribed in federal standard 10 CFR 430.32(k)(2).

# Residential Installed Measures

## Appliances

### 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 60 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 60. Example Residential Heat Pump Clothes Dryer CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ENERGY STAR Most Efficient? | Baseline Dryer Fuel | Lifetime CO2e Reductions,  Thermal Sector [g] | Lifetime CO2e Reductions,  Total [g] | Lifetime Credits |
| No | Natural Gas |  |  |  |
| Propane |  |  |  |
| Unknown |  |  |  |
| Yes | Natural Gas |  |  |  |
| Propane |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect + ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase dryer – CO2ehp dryer

CO2ebase dryer = Annual CO2e emissions [g] from baseline dryer

If baseline dryer fuel is known:

Propane: CO2ebase dryer = Ebase dryer x (CILP + CI’LP)

Natural gas: CO2ebase dryer = (Ebase dryer x CING) / (1 – TDLNG)

Ebase dryer = Baseline dryer energy usage = Load / CEFbase x 3.6

CEFbase = Minimum Combined Energy Factor (CEF) for vented gas dryer [lbs/kWh] = 2.84.[[207]](#footnote-207)

If baseline dryer fuel is unknown:

CO2ebase dryer = (((%Elecdf x Load x CIelec)/CEFave,elec)/(1-TDLelec) + ((%NGdf x Load x CING)/CEFave,NG)/(1-TDLNG) + (%LPdf x Loadx (CILP+CI’LP))/CEFave,LP) x 3.6

Ebase dryer = ((%Elecdf x Load)/CEFave,elec + (%NGdf x Load)/CEFave,NG + (%LPdf x Load)/CEFave,LP) x 3.6

%Elecdf, etc. = Relative proportion of fuel in Vermont’s dryer fuel mix. See Table 61.[[208]](#footnote-208)

CEFave = Average Combined Energy Factor (CEF) of baseline dryers by fuel. See Table 61.[[209]](#footnote-209)

Table 61. Clothes Dryer Fuel Mix and Average Efficiency, Residential Buildings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Dryer Fuel | Building Type | | | Assumed Dryer Efficiency (CEFave,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 |

CO2ehp dryer = Annual CO2e emissions [g] from heat pump or hybrid dryer = (Ehp dryer x CIelec) / (1 – TDLelec)

Ehp dryer = Load / CEFhp x 3.6

CEFhp = CEF of the heat pump dryer unit based on type and ENERGY STAR level. [[210]](#footnote-210)

Table 62. Heat Pump Clothes Dryer CEFby Type (CEFhp)

| Technology | Size | CEFhp [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

Load = Annual clothes drying load [lbs] = Weight x Ncycles

Weight = Average clothes dryer load weight [lbs]. [[211]](#footnote-211)

Table 63. Average Load Weight by Dryer Size

| Dryer Size | Average Weight [lbs] |
| --- | --- |
| Standard (≥ 4.4 ft3) | 8.45 |
| Compact (< 4.4 ft3) | 3.00 |

Ncycles = Number of dryer cycles per year = 322.[[212]](#footnote-212)

Space Heating Impacts

If the primary space heating fuel is known:

Oil: ΔCO2eheat = (ΔEhl x (CIoil + CI’oil)) / ηave,oil

Propane: ΔCO2eheat = (ΔEhl x (CILP + CI’LP)) / ηave,LP

Natural Gas: ΔCO2eheat = ((ΔEhl x CING ) / ηave,NG)/(1-TDLNG)

Wood: CO2ewood = (ΔEhl x (CIwood + CI’wood)) / ηave,wood

If the primary space heating fuel is unknown:

ΔCO2eheat = ((%Oil x ΔEhl x (CIoil+CI’oil))/ηave,oil) + ((%LP x ΔEhl x (CILP+CI’LP)) /ηave,LP) + ((%NG x ΔEhl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x ΔEhl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x ΔEhl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 64)[[213]](#footnote-213)

ηave,fuel = Average heating efficiency for each fuel type [dimensionless] (see Table 64)[[214]](#footnote-214)

Table 64. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Heating Fuel | Building Type | | | Average Heating Efficiency (ηave,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:

ΔEhl = (WHHF x %Conditioned)x ((HRbase x Ebase dryer) – (HRhp x Ehp dryer))

WHHF = Portion of reduced waste heat that results in increased heating = 0.558.[[215]](#footnote-215)

%Conditioned = Portion of homes with dryer in conditioned space = 73%.[[216]](#footnote-216)

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool  = Space cooling impacts [g] = (ΔEcl x CIelec) /ηcool / (1 – TDLelec)

ηcool = Cooling system efficiency = 3.72.[[217]](#footnote-217)

Change in Cooling load:

ΔEcl = (WHCF x %Cool)x ((HRbase x Edryer,base) – (HRhp x Edryer,hp))

WHCF = Portion of waste heat that results in increased cooling= 0.188 [[218]](#footnote-218)

%Cool = Percent of Vermont homes with central cooling[[219]](#footnote-219)

Table 65. Percentage of Residential Customers with Central Cooling

| Central Cooling? | %Cool | |
| --- | --- | --- |
| Early Replacement | New Construction |
| Yes | 100% | |
| No | 0% | |
| Unknown, Single Family | 15% | 41% |
| Unknown, Multifamily | 12% | 41% |
| Unknown, Unknown Building Type | 14.7% | 41% |

**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 66. Portion of Dryer Heat Energy Remaining in Space

| Dryer Type | %HR [[220]](#footnote-220) |
| --- | --- |
| Vented | 5% |
| Ventless | 100% |

3.6 = MJ per kWh

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is estimated to be 12 years.[[221]](#footnote-221)

#### Measure Cost

The market opportunity incremental cost is $61 for ENERGY STAR units and $412 for ENERGY STAR Most Efficient Units.[[222]](#footnote-222)

#### 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.

### 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 67 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 67. Example Induction Cooktop CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| Existing Cooktop | Lifetime CO2e Reductions,  Thermal Sector [g] | Lifetime CO2e Reductions,  Total [g] | Lifetime Credits |
| Natural Gas |  |  |  |
| Propane |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 clean heat credit per metric ton of CO2e reductions.

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2einduction

CO2ebase = Annual CO2e emissions [g] of baseline cooktop:

If baseline fuel is known:

Propane: CO2ebase = Ebase,LP x (CILP + CI’LP)

Natural Gas: CO2ebase = Ebase,NG x CING/(1 – TDLNG)

If baseline fuel is unknown:

CO2ebase = (%LPcook x Ebase,LP x(CILP+CI’LP)) + (%NGcook x Ebase,NG x CING)/(1-TDLNG) + (%Eleccook x Ebase,elec x CIelec)/(1-TDLelec)

%LP, etc. = Relative proportion of cooktop fuel in Vermont residential buildings[[223]](#footnote-223)

Table 68. 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% |
| Natural Gas (NG) | 12% | 42% | 15% |

CO2einduction = Annual CO2e emissions of electric induction cooktop [g] =

(Einduction x CIelec) / (1 – TDLelec)

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs:**

Ebase = Energy consumption of baseline cooktop in megajoules [MJ]

= (Heat Up Energy + Simmer Energy + Saute Energy) x Days. See Table 69. Standard electric derived from induction cooktop values assuming cooking efficiencies of 0.74 and 0.84, respectively. [[224]](#footnote-224)

Einduction = Energy consumption of electric induction cooktop [MJ]

= (Heat Up Energy + Simmer Energy + Saute Energy) x Days. See Table 69.

Table 69. Cooktop Energy Usage

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Cooktop Fuel[[225]](#footnote-225) | Heat Up Energy [MJ/Day] | Simmer Energy [MJ/Day] | Saute Energy [MJ/Day] | Total Energy [MJ/Day]  (Ebase, Einduction) |
| 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.[[226]](#footnote-226)

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The measure life for an induction cooktop is 15 years.[[227]](#footnote-227)

#### Measure Cost

Retrofit: The actual installed cost of the induction cooktop should be used if possible; if unknown, assume $2,100. [[228]](#footnote-228)

MOP:

* Assume an incremental cost of $300 for replacing standard electric cooktops, and $200 for replacing natural gas or propane cooktops.[[229]](#footnote-229)
* Assume an incremental cost of $247 if the existing cooktop fuel is unknown.[[230]](#footnote-230)

#### 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.

## Building Envelope

### 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. See ERV/HRV measure characterization.

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 70 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 71 (known systems/fuels) or per Table 72 (unknown systems/fuels)
* Building type (single family or multifamily) is unknown/not collected

Table 70. Example Residential Air Sealing CO2e Reductions

| CFM50 Reduction | | System Type | Fuel | Lifetime CO2e Reductions, Thermal [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
| --- | --- | --- | --- | --- | --- | --- |
| Range | Assumed Value |
| > 0 and < 800 | 400 | Boiler | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Kerosene |  |  |  |
| Furnace | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Kerosene |  |  |  |
| Heat Pump | Electric |  |  |  |
| Baseboard | Electric |  |  |  |
| Pellet Stove | Wood |  |  |  |
| Unknown | Unknown |  |  |  |
| 800 to < 1600 | 1200 | Boiler | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Kerosene |  |  |  |
| Furnace | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Kerosene |  |  |  |
| Heat Pump | Electric |  |  |  |
| Baseboard | Electric |  |  |  |
| Pellet Stove | Wood |  |  |  |
| Unknown | Unknown |  |  |  |
| > 1600 | 2000 | Boiler | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Kerosene |  |  |  |
| Furnace | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Kerosene |  |  |  |
| Heat Pump | Electric |  |  |  |
| Baseboard | Electric |  |  |  |
| Pellet Stove | Wood |  |  |  |
| Unknown | Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Total annual carbon dioxide equivalent emissions reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = CO2e emissions reductions [g] from reducing heating energy

If primary heating fuel is known:

Oil: ΔCO2eheat = ΔEhl / ηheat x (CIoil + CI’oil)

Propane: ΔCO2eheat = ΔEhl / ηheat x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = (ΔEhl / ηheat x CING)/ (1 – TDLNG)

Kerosene: ΔCO2eheat = ΔEhl / ηheat x (CIkerosene + CI’kerosene)

Wood: ΔCO2eheat = ΔEhl / ηheat x (CIwood + CI’wood)

Electricity: ΔCO2eheat = (ΔEhl / ηheat x CIelec)/ (1 – TDLelec)

ηheat = Heating system efficiency, dependent on fuel and system type[[231]](#footnote-231):

Table 71. Residential Deemed Heating System Efficiencies

|  |  |  |
| --- | --- | --- |
| System Type | Fuel | Heating Efficiency (ηheat) |
| 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:

ΔCO2eheat = (%Oil x ΔEhl x (CIoil+CI’oil)/ηave,oil) + (%LP x ΔEhl x (CILP+CI’LP)) /ηave,LP) + (%NG x ΔEhl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x ΔEhl x CIelec) /ηave,elec)/(1-TDLelec) + (%Wood x ΔEhl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 72)[[232]](#footnote-232)

ηave,fuel = Average heating efficiency for each fuel type [dimensionless] (see Table 72)[[233]](#footnote-233)

Table 72. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency (ηave,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 |

ΔEhl = Reduction in heating load [MJ] = [(1.08 x (CFM50pre – CFM50post) / N x Adjheat x HDH)] x 0.00106

Adjheat = Heating adjustment factor to reconcile this simplified algorithm with evaluation bill analysis results = 0.55 [dimensionless].[[234]](#footnote-234)

HDH = Heating degree hours [°F hr] = 113,443.[[235]](#footnote-235)

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool = CO2e reductions [g] from decreased cooling energy = (ΔEcl/ηcool x CIelec)/(1-TDLelec)

ΔEcl = Reduction in cooling load [MJ] = [%Cool x (1.08 x (CFM50pre – CFM50post) / N x Adjcool x CDH)] x 0.00106

%Cool = Percent of Vermont existing homes with central cooling.[[236]](#footnote-236)

|  |  |
| --- | --- |
| Central Cooling? | %Cool |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 15% |
| Unknown, Multifamily | 12% |
| Unknown, Building Type Unknown | 14.70% |

Adjcool = 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].[[237]](#footnote-237)

CDH = Cooling degree hours [°F hr] = 6,619.[[238]](#footnote-238)

ηcool = Cooling system efficiency = 3.72.[[239]](#footnote-239)

ΔCO2efan = CO2e reductions [g] from decreased furnace fan or boiler pump energy = (ΔEfan x CIelec)/(1-TDLelec)

ΔEfan = Reduction in furnace fan or boiler pump energy [MJ]

If heating fuel is known:

ΔEfan = %Fossil x ΔEhl/ηheat x Fe

If heating fuel is unknown:

ΔEfan = %Fossil x ((%Oil x ΔEhl/ηave,oil) + (%LP x ΔEhl/ηave,LP) + (%NG x ΔEhl/ηave,NG) + (%Elec x ΔEhl /ηave,elec) + (%Wood x ΔEhl /ηave,wood)) x Fe

%Fossil = Percent of Vermont homes with fossil-fuel furnaces or boilers (from Table 72).

|  |  |
| --- | --- |
| Fossil Fuel System? | %Fossil |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 85% |
| Unknown, Multifamily | 76% |
| Unknown, Building Type Unknown | 84% |

Fe = Furnace/boiler fan/pump energy as a percentage of annual fuel consumption = 3.14%.[[240]](#footnote-240)

**Common Inputs:**

CFM50pre = Pre-installation blower door reading in cubic feet per minute, measured at 50 Pascals pressure differential.

CFM50post = 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].[[241]](#footnote-241)

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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

Lifetime for air sealing is 20 years.[[242]](#footnote-242)

#### Measure Cost

Measure cost of $3,000 per job is assumed for air sealing.[[243]](#footnote-243)

#### 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 (CFM50pre)
* Post-installation blower door measurement at 50 Pascals pressure differential (CFM50post)

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 insulation standards.

### 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 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
* Building type (single family or multifamily) is unknown/not collected

Table 73. 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 |  |  |  |
| Propane | None | R-49 |  |  |  |
| Natural Gas | None | R-49 |  |  |  |
| Kerosene | None | R-49 |  |  |  |
| Furnace | Oil | None | R-49 |  |  |  |
| Propane | None | R-49 |  |  |  |
| Natural Gas | None | R-49 |  |  |  |
| Kerosene | None | R-49 |  |  |  |
| Heat Pump | Electric | None | R-49 |  |  |  |
| Baseboard | Electric | None | R-49 |  |  |  |
| Pellet Stove | Wood | None | R-49 |  |  |  |
| Unknown | Unknown | None | R-49 |  |  |  |
| Exterior Wall, Standard Wood Framing | Boiler | Oil | None | R-15 |  |  |  |
| Propane | None | R-15 |  |  |  |
| Natural Gas | None | R-15 |  |  |  |
| Kerosene | None | R-15 |  |  |  |
| Furnace | Oil | None | R-15 |  |  |  |
| Propane | None | R-15 |  |  |  |
| Natural Gas | None | R-15 |  |  |  |
| Kerosene | None | R-15 |  |  |  |
| Heat Pump | Electric | None | R-15 |  |  |  |
| Baseboard | Electric | None | R-15 |  |  |  |
| Pellet Stove | Wood | None | R-15 |  |  |  |
| Unknown | Unknown | None | R-15 |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Total annual carbon dioxide equivalent emissions reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = CO2e emissions reductions [g] from reducing heating energy

If primary heating fuel is known:

Oil: ΔCO2eheat = ΔEhl / ηheat x (CIoil + CI’oil)

Propane: ΔCO2eheat = ΔEhl / ηheat x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = (ΔEhl / ηheat x CING)/ (1 – TDLNG)

Kerosene: ΔCO2eheat = ΔEhl / ηheat x (CIkerosene + CI’kerosene)

Wood: ΔCO2eheat = ΔEhl / ηheat x (CIwood + CI’wood)

Electricity: ΔCO2eheat = (ΔEhl / ηheat x CIelec)/ (1 – TDLelec)

ηheat = Heating system efficiency, dependent on fuel and system type[[244]](#footnote-244):

Table 74. Residential Deemed Heating System Efficiencies

|  |  |  |
| --- | --- | --- |
| System Type | Fuel | Heating Efficiency (ηheat) |
| 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:

ΔCO2eheat = (%Oil x ΔEhl x (CIoil+CI’oil)/ηave,oil) + (%LP x ΔEhl x (CILP+CI’LP)) /ηave,LP) + (%NG x ΔEhl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x ΔEhl x CIelec) /ηave,elec)/(1-TDLelec) + (%Wood x ΔEhl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 75)[[245]](#footnote-245)

ηave,fuel = Average heating efficiency for each fuel type [dimensionless] (see Table 75)[[246]](#footnote-246)

Table 75. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Heating Fuel | Building Type | | | Average Existing Heating Efficiency (ηave,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 |

ΔEhl**=** Reduction in heating load [MJ] = ((1/Rpre – 1/Rpost) x Ains x HDH x Adjheat) x 0.00106

HDH = Heating degree hours [°F hr], dependent on structure being treated (see below) [[247]](#footnote-247)

| Structure | HDH [°F hr] |
| --- | --- |
| Flat attic or sloped ceiling | 127,961.3 |
| Exterior walls |
| Basement walls | 99,194.6 |

Adjheat = Heating adjustment factor to reconcile this simplified algorithm with evaluation bill analysis results = 0.55 [dimensionless].[[248]](#footnote-248)

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool = CO2e reductions [g] from decreased cooling energy = (ΔEcl/ηcool x CIelec)/(1-TDLelec)

ΔEcl = Reduction in cooling load [MJ] = [%Cool x (1.08 x (CFM50pre – CFM50post) / N x Adjcool x CDH)] x 0.00106

%Cool = Percent of Vermont existing homes with central cooling.[[249]](#footnote-249)

|  |  |
| --- | --- |
| Central Cooling? | %Cool |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 15% |
| Unknown, Multifamily | 12% |
| Unknown, Building Type Unknown | 14.70% |

Adjcool = 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].[[250]](#footnote-250)

CDH = Cooling degree hours [°F hr] = 6,619.[[251]](#footnote-251)

ηcool = Cooling system efficiency = 3.72.[[252]](#footnote-252)

ΔCO2efan = CO2e reductions [g] from decreased furnace fan or boiler pump energy = (ΔEfan x CIelec)/(1-TDLelec)

ΔEfan = Reduction in furnace fan or boiler pump energy [MJ]

If heating fuel is known:

ΔEfan = %Fossil x ΔEhl/ηheat x Fe

If heating fuel is unknown:

ΔEfan = %Fossil x ((%Oil x ΔEhl/ηave,oil) + (%LP x ΔEhl/ηave,LP) + (%NG x ΔEhl/ηave,NG) + (%Elec x ΔEhl /ηave,elec) + (%Wood x ΔEhl /ηave,wood)) x Fe

%Fossil = Percent of Vermont homes with fossil-fuel furnaces or boilers (from Table 75).

|  |  |
| --- | --- |
| Fossil Fuel System? | %Fossil |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 85% |
| Unknown, Multifamily | 76% |
| Unknown, Building Type Unknown | 84% |

Fe = Furnace/boiler fan/pump energy as a percentage of annual fuel consumption = 3.14%.[[253]](#footnote-253)

**Common Inputs:**

Rpre = 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.

Rpost = 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.[[254]](#footnote-254)

Table 76. Residential Insulation: Assembly R-Factors for Attic Roofs with Wood Joists

|  |  |
| --- | --- |
| Rated R-Value of Insulation Alone | Overall R-Factor For Entire Assembly (Rpre, Rpost) |
| 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 77. 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) (Rpre, Rpost) | | | | |
| 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 |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| 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 78. 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 Gpysum 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 Gpysum 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 |

Ains = 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### 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.[[255]](#footnote-255)

#### 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. [[256]](#footnote-256)

#### 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 (Ains)
* 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

## Domestic Hot Water

### 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):[[257]](#footnote-257)

Table 79. NEEA Residential HPWH Minimum CCE Requirements

| Tier | Minimum CCE |
| --- | --- |
| Tier 1 | 2.0 |
| 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 80 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 81
* Average space heating efficiencies per Table 82
* Tier 1 Residential HPWH, CCEHPWH = 2.0
* Building type (single family or multifamily) is unknown/not collected

Table 80. Example Residential Heat Pump Water Heater CO2e Reductions

| Baseline Water Heating Fuel | Proposed Equipment | Space Heating Fuel | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions, Total [g] | | Lifetime Credits | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Oil | HPWH  Tier 1 | Oil |  | |  | |  |
| Propane |  | |  | |  |
| Natural Gas |  | |  | |  |
| Electricity |  | |  | |  |
| Wood |  | |  | |  |
| Unknown |  | |  | |  |
| Propane | HPWH  Tier 1 | Oil |  | |  | |  |
| Propane |  | |  | |  |
| Natural Gas |  | |  | |  |
| Electricity |  | |  | |  |
| Wood |  | |  | |  |
| Unknown |  | |  | |  |
| Natural Gas | HPWH  Tier 1 | Oil |  | |  | |  |
| Propane |  | |  | |  |
| Natural Gas |  | |  | |  |
| Electricity |  | |  | |  |
| Wood |  | |  | |  |
| Unknown |  | |  | |  |
| Unknown | HPWH  Tier 1 | Oil |  | |  | |  |
| Propane |  | |  | |  |
| Natural Gas |  | |  | |  |
| Electricity |  | |  | |  |
| Wood |  | |  | |  |
| Unknown |  | |  | |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect + ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase - CO2eHPWH

CO2ebase = Annual CO2e emissions [g] from baseline water heater

If baseline water heater fuel is known:

Oil: ΔCO2eheat = Qload / EFave,oil x (CIoil + CI’oil)

Propane: ΔCO2eheat = Qload / EFave,LP x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = Qload / EFave,LP x CING / (1 – TDLNG)

If baseline water heater fuel is unknown:

CO2ebase = ((%OilWH x Qload x (CIoil+CI’oil))/EFave,oil) + ((%LPWH x Qload x (CILP+CI’LP)) /EFave,LP) + ((%NGWH x Qload x CING) /EFave,NG)/(1-TDLNG) + ((%ElecWH x Qload x CIelec) /EFave,elec)/(1-TDLelec)

%OilWH, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 81)[[258]](#footnote-258)

EFave = 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.[[259]](#footnote-259)

Table 81. Vermont Water Heating Fuel Mix and Average Efficiency, Residential Buildings

|  |  |  |
| --- | --- | --- |
| Water Heating Fuel | %Fuelwh | Average  Water Heater Efficiency  (EFave,fuel) |
| Oil | 9% | 0.71 |
| Propane (LP) | 24% | 0.71 |
| Natural Gas (NG) | 23% | 0.71 |
| Electricity | 43% | 1.34 |

CO2eHPWH = Annual CO2e emissions [g] from heat pump water heater = (Qload / CCEHPWH x CIelec) / (1 – TDLelec)

CCEHPWH = NEEA HPWH Cool Climate Efficiency (CCE) rating. Use actual or assume minimum CCE based on tier. See Table 79.

ΔCO2eheat = 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:

Oil: ΔCO2eheat = (ΔEhl / ηave,oil) x (CIoil + CI’oil)

Propane: ΔCO2eheat = (ΔEhl / ηave,LP)x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = (ΔEhl / ηave,NG) x (CING / (1 – TDLNG))

If primary space heating fuel is unknown:

ΔCO2eheat = ((%OilSH x ΔEhl  x (CIoil+CI’oil))/ηave,oil) + ((%LPSH x ΔEhl x (CILP+CI’LP)) /ηave,LP) + ((%NGSH x ΔEhl x CING) /ηave,NG)/(1-TDLNG) + ((%ElecSH x ΔEhl x CIelec) /ηave,elec)/(1-TDLelec) + ((%WoodSH x ΔEhl x (CIwood+ CI’wood)) /ηave,wood)

%OilSH, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 82)[[260]](#footnote-260)

ηave,oil, etc. = Average heating efficiency for each fuel type [dimensionless] (see Table 82)[[261]](#footnote-261)

Table 82. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Space Heating Fuel | Building Type | | | Average Space Heating Efficiency (ηave,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 |

ΔEhl = Space heating load change = −(Qload x IF) / CCEHPWH

IF = Interactive factor, portion of HPWH ambient cooling impact that results in increased space heating = 0.542.[[262]](#footnote-262)

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

Qload = Annual water heating load [MJ] = 9,536.[[263]](#footnote-263)

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 12 years.[[264]](#footnote-264)

#### Measure Cost

The assumed full retrofit cost of installation is below.[[265]](#footnote-265)

|  |  |
| --- | --- |
| HPWH Tank Size [gal] | Installed Cost |
| ≤ 55 | $2,087 |
| > 55 | $2,820 [[266]](#footnote-266) |

#### Program Data Tracking Recommendations

The following variables should be tracked for this measure:

* Cool Climate Efficiency of proposed heat pump water heater (CCEHPWH) 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.

### 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, 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.[[267]](#footnote-267)

New Construction: New standard flow rate faucet aerator rated at 1.5 GPM.[[268]](#footnote-268)

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.

New Construction:Faucet aerator rated at 1.3 GPM [[269]](#footnote-269)

#### 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 83 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 84
* Water heater efficiencies per Table 84

Table 83. Example Residential Low Flow Faucet Aerator CO2e Reductions

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Program Delivery Type | Faucet Type | Baseline Aerator | Proposed Aerator | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions,  Total [g] | Lifetime Credits |
| Direct Install | Kitchen | 2.2 GPM | 1.5 GPM |  |  |  |
| Bath | 2.2 GPM | 1.0 GPM |  |  |  |
| New Construction | Kitchen | 1.5 GPM | 1.3 GPM |  |  |  |
| Bath | 1.5 GPM | 1.3 GPM |  |  |  |
| Free Products | Kitchen | 2.2 GPM | 1.5 GPM |  |  |  |
| Bath | 2.2 GPM | 1.0 GPM |  |  |  |
| Dropship | Kitchen | 2.2 GPM | 1.5 GPM |  |  |  |
| Bath | 2.2 GPM | 1.0 GPM |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector Decarbonization Impacts:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement

If water heater fuel is known:

Oil: ΔCO2edirect = (ΔEwhl x (CIoil + CI’oil)) / REoil

Propane: ΔCO2edirect = (ΔEwhl x (CIoil + CI’oil)) / RELP

Natural Gas: ΔCO2edirect = ((ΔEwhl x CING) / RENG) / (1 – TDLNG)

Electricity: ΔCO2edirect = ((ΔEwhl x CIelec) / REelec) / (1 – TDLelec)

If water heater fuel is unknown:

ΔCO2e = (%Oil x ΔEwhl x (CIoil + CIoil))/REoil + (%LP x ΔEwhl x (CILP + CI’LP)) / RELP + (%NG x ΔEwhl x CING)/ RENG)/(1-TDLNG) + (%Elec x ΔEwhl x CIelec)/ REelec)/(1-TDLelec)

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 84)[[270]](#footnote-270)

REoil etc. = Average water heater recovery efficiency by fuel type (see Table 84)[[271]](#footnote-271)

Table 84. Vermont Water Heating Fuel Mix and Average Recovery Efficiency, Residential Buildings

|  |  |  |
| --- | --- | --- |
| Water Heating Fuel | %Fuel | Recovery Efficiency (REfuel) |
|
| Oil | 9% | 0.83 |
| Propane (LP) | 24% | 0.83 |
| Natural Gas | 23% | 0.83 |
| Electricity | 43% | 1.71 |

ΔEwhl = Reduction in water heating load [MJ] = ((GPMBase x ThrottleBase – GPMLow x ThrottleLow) x (Minutes/Person/Day) x (People/Household) x (Days/Year) x DR / (Faucets/Home) x 8.3 x (TFaucet – Tinlet) x ISR) x 0.00106

GPMBase = Flow rate of existing faucet aerator = 2.2 GPM for retrofit; 1.5 GPM for new construction

GPMLow = 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

= 1.5 GPM for free products

Throttle­Base = Percentage of full-throttle flow rate for baseline faucet = 83% [[272]](#footnote-272)

ThrottleLow = Percentage of full-throttle flow rate for low flow faucet = 95% [[273]](#footnote-273)

Minutes/Person/Day = Average length of faucet use per person = 1.6 (bathroom); 4.5 (kitchen)[[274]](#footnote-274)

People/Household = Average number of people per household = 2.30 [[275]](#footnote-275)

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)[[276]](#footnote-276)

Faucets/Home = Average number of faucet fixtures per household = 2.83 (SF bathroom); 1.5 (MF bathroom); 1.0 (kitchen)[[277]](#footnote-277)

TFaucet = Mixed water temperature (°F) of hot water coming from faucet = 86°F (bathroom); 93°F (kitchen)[[278]](#footnote-278)

Tinlet = Inlet water temperature (°F) of water entering the household = 51.8°F[[279]](#footnote-279)

ISR = In-service rate, the percentage of incentivized units actually installed [[280]](#footnote-280)

Table 85. 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life of installed equipment is estimated to be 10 years.[[281]](#footnote-281)

#### 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.[[282]](#footnote-282)

#### 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 (GPMLow)
* Water heater fuel

Free Giveaways:

* Aerator flow: 1.0, 1.3, or 1.5 GPM (GPMLow)

#### Energy Codes and Standards

The baseline assumption for new construction is assumed to be the state standard which took effect on 7/1/2020[[283]](#footnote-283).

* + - 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.

### 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, 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.[[284]](#footnote-284)

New Construction: New standard flow rate showerhead rated at 2.0 GPM. [[285]](#footnote-285)

**Proposed Conditions**

Direct Install, Giveaways, and Dropship: Low flow showerhead rated at 1.5 GPM. [[286]](#footnote-286)

New Construction: Showerhead rated at 1.8 GPM [[287]](#footnote-287)

#### 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>).

#### 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 is unknown/not collected

Table 86. Example Residential Low Flow Showerhead CO2e Reductions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Program Delivery Type | Baseline Showerhead | Proposed Showerhead | Lifetime CO2e Reductions, Thermal Sector [g] | Lifetime CO2e Reductions,  Total [g] | Lifetime Credits |
| Direct Install | 2.5 GPM | 1.5 GPM |  |  |  |
| New Construction | 2.0 GPM | 1.8 GPM |  |  |  |
| Free Products | 2.5 GPM | 1.5 GPM |  |  |  |
| Dropship | 2.5 GPM | 1.5 GPM |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement

If water heater fuel is known:

Oil: ΔCO2edirect = (ΔEwhl x (CIoil + CI’oil)) / REoil

Propane: ΔCO2edirect = (ΔEwhl x (CIoil + CI’oil)) / RELP

Natural Gas: ΔCO2edirect = ((ΔEwhl x CING) / RENG) / (1 – TDLNG)

Electricity: ΔCO2edirect = ((ΔEwhl x CIelec) / REelec) / (1 – TDLelec)

If water heater fuel is unknown:

ΔCO2e = (%Oil x ΔEwhl x (CIoil + CIoil))/REoil + (%LP x ΔEwhl x (CILP + CI’LP)) / RELP + (%NG x ΔEwhl x CING)/ RENG)/(1-TDLNG) + (%Elec x ΔEwhl x CIelec)/ REelec)/(1-TDLelec)

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 87)[[288]](#footnote-288)

REoil etc. = Average water heater recovery efficiency by fuel type (see Table 87)[[289]](#footnote-289)

Table 87. Vermont Water Heating Fuel Mix and Average Recovery Efficiency, Residential Buildings

|  |  |  |
| --- | --- | --- |
| Water Heating Fuel | %Fuel | Recovery Efficiency (REfuel) |
|
| Oil | 9% | 0.83 |
| Propane (LP) | 24% | 0.83 |
| Natural Gas | 23% | 0.83 |
| Electricity | 43% | 1.71 |

ΔEwhl = Reduction in water heating load [MJ]

= (((GPMBase - GPMLow) x (Minutes/Shower) x (People/Household) x (Showers/Person/Day) x (Days/Year) / (Showerheads/Home) x 8.3 x (TSh – Tinlet) x ISR) x 0.00106

GPMBase = Flow rate of existing showerhead = 2.5 for early replacement; 2.0 GPM for new construction.

GPMLow = 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 [[290]](#footnote-290)

People/Household = Average number of people per household = 2.30 [[291]](#footnote-291)

Showers/Person/Day = Number of showers per person per day = 0.6 285

Days/Year = Days the showerhead is used per year = 365[[292]](#footnote-292)

Showerheads/Home = Average number of showerhead fixtures per household = 1.79 (SF existing) [[293]](#footnote-293); 1.30 (MF existing) [[294]](#footnote-294) ; (1.74 unknown)[[295]](#footnote-295); 2.1 GPM (RNC)[[296]](#footnote-296)

TSh = Mixed water temperature (°F) of hot water coming from showerhead = 101°F [[297]](#footnote-297)

Tinlet = Inlet water temperature (°F) of water entering the household = 51.8°F [[298]](#footnote-298)

ISR = In-service rate representing the number of units installed[[299]](#footnote-299)

Table 88. 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life of installed equipment is estimated to be 10 years. [[300]](#footnote-300)

#### 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.[[301]](#footnote-301)

#### 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 (GPMLow)
* Water heater fuel

Free Giveaways:

* Showerhead flow: 1.5 GPM or 1.8 GPM (GPMLow)

#### Energy Codes and Standards

The baseline assumption for new construction is assumed to be the state standard which took effect on 7/1/2020[[302]](#footnote-302).

* + - 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.

### 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).[[303]](#footnote-303)

#### Decarbonization Summary

Table 89 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:

* Baseline and backup water heater fuels are the same
* Baseline water heater efficiency by fuel per Table 90

Table 89. Example Residential Solar Water Heater CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| Backup Fuel | SUEF Range | Assumed SUEF | Lifetime CO2e reductions [g] |
| Oil | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |
| Natural Gas | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |
| Propane | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |
| Electricity | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |
| Unknown | 1.0 to < 1.5 | 1.25 |  |
| 1.5 to < 2.0 | 1.75 |  |
| 2 to < 2.5 | 2.25 |  |
| 2.5 or greater | 3.00 |  |

#### Decarbonization and Energy impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 clean heat credit per metric ton of CO2e reductions.

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eswh

CO2ebase = Annual CO2e emissions [g] from baseline water heater

If baseline water heater fuel is known:

Oil: CO2ebase = (Qload x (CIoil+CI’oil)/UEFmin,oil)

Propane: CO2ebase = (Qload x (CILP+CI’LP)/UEFmin,LP

Natural Gas: CO2ebase = (Qload / UEFmin,NG) / (1 – TDLNG)

Electricity: CO2ebase = (Qload / UEFmin,elec) / (1 – TDLelec)

If baseline water heater fuel is unknown:

CO2ebase = ((%OilWH x Qload x (CIoil+CI’oil))/UEFmin,oil) + ((%LPWH x Qload x (CILP+CI’LP)) /UEFmin,LP) + ((%NGWH x Qload x CING) /UEFmin,NG)/(1-TDLNG) + ((%ElecWH x Qload x CIelec) /UEFmin,elec)/(1-TDLelec)

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 90)[[304]](#footnote-304)

UEFmin,oil, etc. = Minimum water heater uniform energy factor (UEF) [dimensionless] by fuel (see Table 90). 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.[[305]](#footnote-305)

Table 90. Vermont Water Heating Fuel Mix and Minimum Heating Efficiency, Residential Buildings

|  |  |  |
| --- | --- | --- |
| Water Heating Fuel | %Fuelwh | Minimum Water Heater Efficiency (UEFmin,fuel) |
| Oil | 11% | 0.53 |
| Propane | 32% | 0.60 |
| Natural Gas | 15% | 0.60 |
| Electricity | 42% | 0.92 |

CO2eswh = Annual CO2e emissions [g] from solar water heater

If backup water heater fuel is known:

Oil: CO2eswh = (Qload x (CIoil+CI’oil)/SUEF)

Propane: CO2eswh = (Qload x (CILP+CI’LP)/SUEF

Natural Gas: CO2eswh = (Qload / SUEF x CING) / (1 – TDLNG)

Electricity: CO2eswh = (Qload / SUEF x CIelec) / (1 – TDLelec)

If backup water heater fuel is unknown:

CO2eSWH = ((%Oil x Qload x (CIoil+CI’oil))/SUEF) + ((%LP x Qload x (CILP+CI’LP)) /SUEF) + ((%NG x Qload x CING) /SUEF)/(1-TDLNG) + ((%Elec x Qload x CIelec) /SUEF)/(1-TDLelec)

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**

Qload = Annual water heating load [MJ] = 9,536.[[306]](#footnote-306)

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

20 years[[307]](#footnote-307)

#### Measure Cost

* Retrofit: Use actual installed cost of SWH if available, or assume $6,000 for planning purposes.[[308]](#footnote-308)
* MOP: Determine incremental cost of SWH compared to a conventional gas or electric storage water heater. Default value is $4,731.[[309]](#footnote-309)

#### 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)

#### Energy Codes and Standards

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

## HVAC

### 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, 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.[[310]](#footnote-310)

**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 communication and exceed the typical performance of manual and conventional programmable thermostats through the automatic or default capabilities described above.[[311]](#footnote-311)

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 91 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 94):
  + - Retrofit: 67,307 Btu/h
    - New Construction: 40,237

Table 91. Example Residential Advanced Thermostat CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Decision/Action Type | Heating Fuel | Lifetime CO2e Reductions, Thermal [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
| Retrofit | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electricity |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |
| New Construction | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electricity |  |  |  |
| Unknown |  |  |  |
| Wood |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Total annual carbon dioxide equivalent emissions reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = CO2e emissions reductions from reducing heating energy

If heating fuel is known:

Oil: ΔCO2eheat = ΔEheat x (CIoil + CI’oil)

Propane: ΔCO2eheat = ΔEheat x (CILP + CI’LP)

Natural Gas: ΔCO2eheat = (ΔEheat x CING)/ (1 – TDLNG)

Wood: ΔCO2eheat = ΔEheat x (CIwood + CI’wood)

Electricity: ΔCO2eheat = (ΔEheat x CIelec)/ (1 – TDLelec)

If heating fuel is unknown:

ΔCO2eheat = (%Oil x ΔEheat x (CIoil+CI’oil)) + (%LP x ΔEheat x (CILP+CI’LP)) + (%NG x ΔEheat x CING)/(1-TDLNG) + (%Elec x ΔEheat x CIelec)/(1-TDLelec) + (%Wood x ΔEheat x (CIwood+ CI’wood))

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 92)[[312]](#footnote-312)

Table 92. 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% |

ΔEheat = Heating energy reduction [MJ] = (EFLHheat × Btuhin,heat x SFheat x (1 - %CHP)) x 0.00106

EFLHheat = Estimate of annual household equivalent full load heating hours for heating equipment

Table 93. Residential Advanced Thermostat EFLHheat

| Decision/Action Type | EFLHheat [[313]](#footnote-313) |
| --- | --- |
| Retrofit | 878 |
| New Construction | 855 |

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

For fossil fuel system, use rated if known, or defaults in Table 94.

For heat pump system, Btuhin,heat =Btuhout,heat / COPheat where Btuhout,heat = rated heating output capacity at 47°F in Btu/h. Use rated output capacity if known, or defaults in Table 95. COPheat = Heating coefficient of performance (COP) of heat pump = 3.28.[[314]](#footnote-314)

For wood heater, use defaults in Table 94 or calculate from rated capacity: Btuhin,heat =Btuhout,heat / ηw where ηw = wood heating efficiency. Assume ηw = 65% if unknown.[[315]](#footnote-315)

Table 94. Residential Advanced Thermostat: Input Capacity of Fossil Heating System

| Household Type | Btuhin,heat [[316]](#footnote-316) | |
| --- | --- | --- |
| Retrofit | New Construction |
| Single Family | 70,979 | 41,532 |
| Multifamily | 34,260 | 28,585 |
| Unknown | 67,307 | 40,237 |

Table 95. Residential Advanced Thermostat: Heating Output Capacity of Heat Pump System

| Household Type | Btuhout,heat [[317]](#footnote-317) | |
| --- | --- | --- |
| Retrofit | New Construction |
| Single Family | 80,124 | 44,510 |
| Multifamily | 76,874 | 30,354 |
| Unknown | 79,800 | 43,094 |

SFheat = 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 99.

%CHP= Percentage of customers with central air source or ground source heat pumps as the primary heating system. This variable is used to account for heat pump manufacturer recommendations to limit temperature setbacks during the heating season.[[318]](#footnote-318)

| 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:**

ΔCO2ecool = (ΔEcool x CIelec ) / (1 - TDLelec)

ΔEcool = Cooling energy reduction [MJ] = %Cool x (EFLHcool × Btuhout,cool / COPcool × SFcool) × 0.00106

Btuhout,cool = Output cooling capacity of heat pump or AC in Btu/h

Table 96. Advanced Thermostat Capacity of AC Unit

| Household Type | Capacity [Btu/h] [[319]](#footnote-319) |
| --- | --- |
| Single Family | 37,200 |
| Multifamily | 18,542 |
| Unknown | 35,334 |

%Cool = Percentage of customers with central cooling systems[[320]](#footnote-320)

Table 97. Percentage of Residential Customers with Central Cooling

| Central Cooling? | %Cool | |
| --- | --- | --- |
| Retrofit | New Construction |
| Yes | 100% | |
| No | 0% | |
| Unknown, Single Family | 15% | 41% |
| Unknown, Multifamily | 12% | 41% |
| Unknown, Unknown Building Type | 14.7% | 41% |

EFLHcool = Estimate of annual equivalent full load cooling hours for heat pump or air conditioner = 375.[[321]](#footnote-321)

COPcool = Cooling coefficient of performance for air-conditioner or heat pump

Table 98. Residential Advanced Thermostat: Cooling COP

| Decision/Action Type | COPcool |
| --- | --- |
| Early Replacement[[322]](#footnote-322) | 3.72 |
| New Construction[[323]](#footnote-323) | 4.45 |

SFcool = 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 99.

**Common Inputs**

Table 99. Advanced Thermostat Savings Factors

| Decision/ Action Type | Building Type | Heating Savings Factor[[324]](#footnote-324) | Cooling Savings Factor[[325]](#footnote-325) |
| --- | --- | --- | --- |
| 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

0.00106 = MJ per BTU.

#### Measure Life

The expected measure life of installed equipment is estimated to be 10 years.[[326]](#footnote-326)

#### 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.[[327]](#footnote-327)

#### 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.

### 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:** Thermal Efficiency

**Applicable Baseline Fuels:** Wood Pellets

**Decision/Action Type:** MOP, 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 new or existing residential buildings. 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).

This characterization describes the carbon reductions achieved by replacing a low efficiency central wood heating system with an efficient central wood heating system. Refer to the Wood Heating fuel measure characterizations for the carbon reductions associated with switching from fossil fuel heating to wood heating.

**Baseline Conditions**

MOP: The baseline is assumed to be a new central pellet system with a full load efficiency of 75% HHV.

Retrofit: The baseline is assumed to be an existing wood heating system with a full load efficiency of 65% HHV.

**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 ≥ 85% (HHV) as certified by EPA
* PM2.5 emissions rate < 0.08 lbs/MMBTU as certified by EPA
* Provides central heating and is the primary heating system

#### Decarbonization Summary

Table 100 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:

* Proposed system efficiency is 86% HHV at full load
* Wood pellets only
* Baseline efficiencies
  + - MOP: 75% HHV at full load
    - Retrofit: 65% HHV at full load
* Efficient pellet system meets 90% of the annual heating load for Retrofits, and 100% for MOP/New Construction

Table 100. Example C/I Advanced Wood Heating CO2e Reductions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Decision/  Action Type | Capacity Range  [Btu/h] | Assumed Capacity  [Btu/h] | Lifetime CO2e reductions [g],  Thermal Sector | Lifetime CO2e reductions [g],  Total | Lifetime Credits |
| MOP | 25,000 - 80,000 | 55,000 |  |  |  |
| 80,001 - 150,000 | 101,000 |  |  |  |
| 150,001 - 340,000 | 207,000 |  |  |  |
| Retrofit | 25,000 - 80,000 | 55,000 |  |  |  |
| 80,001 - 150,000 | 101,000 |  |  |  |
| 150,001 - 340,000 | 207,000 |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = Annual CO2e reductions [g] due to more efficient wood pellet system

= ΔEheat x (CIpellet + CI’wood)

ΔEheat = Energy savings from upgrading to efficient wood pellet system in megajoules [MJ]

= (%Pellet x Btuh x EFLH x (1/ηbase – 1/ηeff)) x 0.00106

%Pellet = Percentage of annual heating load provided by pellet system[[328]](#footnote-328)

|  |  |
| --- | --- |
| Decision/Action Type | %Pellet |
| MOP | 100% |
| Retrofit | 90% |

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

EFLH = Heating equivalent full load hours

|  |  |
| --- | --- |
| Decision/Action Type | EFLH |
| MOP[[329]](#footnote-329) | 655 |
| Retrofit[[330]](#footnote-330) | 780.5 |

ηbase = Baseline pellet system efficiency

|  |  |
| --- | --- |
| Decision/Action Type | ηbase |
| MOP[[331]](#footnote-331) | 75% |
| Retrofit[[332]](#footnote-332) | 65% |

ηeff = Efficient pellet system efficiency = 86%.[[333]](#footnote-333)

0.00106 = MJ per BTU.

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is 18 years.[[334]](#footnote-334)

#### Measure Cost

|  |  |  |
| --- | --- | --- |
| Decision/Action Type | Cost Type | Cost |
| MOP[[335]](#footnote-335) | Incremental | $13,322 |
| Retrofit[[336]](#footnote-336) | 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 (ηeff)

#### Energy Codes and Standards

All new wood heating appliances offered for sale in the US are required to meet New Source Performance Standards (NSPS)[[337]](#footnote-337) 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>).

### Advanced Wood Heating – Pellet and Cordwood Stoves

**CHS Measure ID:** RE\_HVAC\_AWHS

**Market Sector:** Residential

**End Use:** HVAC

**Applicable Building Types:** Single Family, Multifamily

**Decarbonization Pathways:** Thermal Efficiency

**Applicable Baseline Fuels:** Wood Pellets, Firewood

**Decision/Action Type:** Retrofit

**Program Delivery Type:** Downstream

#### Measure Description

This measure involves the installation of advanced pellet and firewood stoves in existing C/I buildings to replace older, less efficient wood-burning stoves. 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 PM2.5 emissions rates of at least 70% and no more than 2.0 g/hr, respectively. (PM2.5 refers to “fine particles” having an aerodynamic diameter of 2.5 microns or less.)

This characterization describes the carbon reductions achieved by replacing a low efficiency wood-burning stove with an efficient pellet or firewood stove. Refer to the Wood Heating fuel measure characterizations for the carbon reductions associated with switching from fossil fuel heating to wood heating.

**Baseline Conditions**

The baseline is assumed to be an existing, less efficient wood stove supplementing an existing heating system.

**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 homeowner follows all manufacturer recommendations for regular cleaning to maintain the rated efficiency.

#### Eligibility Criteria

Eligible wood heating systems 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%
* PM2.5 ≤ 2.0 g/hr

#### Decarbonization Summary

Table 101 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 is 76%
* Existing stove efficiency is 52%

Table 101. Example C/I Efficient Wood Stove CO2e Reductions

|  |  |  |  |
| --- | --- | --- | --- |
| New Stove Type | Lifetime CO2e reductions [g],  Thermal Sector | Lifetime CO2e reductions [g],  Total | Lifetime Credits |
| Pellet |  |  |  |
| Cordwood |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = Annual CO2e reductions [g] due to more efficient wood stove

For pellet stoves:

ΔCO2eheat = (Ehl x (CIfirewood + CI’wood))/ηbase – (Ehl x (CIpellet + CI’wood))/ηeff,pellet

For cordwood stoves:

ΔCO2eheat = (Ehl x (CIfirewood + CI’wood))/ηbase – (Ehl x (CIfirewood + CI’wood))/ηeff,cordwood

Ehl = Wood stove heating load in megajoules [MJ] = (%Stove x Capacity x EFLH) x 0.00106

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

| Stove Type | %Stove |
| --- | --- |
| Pellet[[338]](#footnote-338) | 64% |
| Cordwood[[339]](#footnote-339) | 65% |

Capacity = Average capacity of primary space heating system installed in Vermont homes [Btu/h] = 91,562. [[340]](#footnote-340)

EFLH = Heating equivalent full load hours for stove = 1,400.[[341]](#footnote-341)

ηbase = Existing stove efficiency = 52%.[[342]](#footnote-342)

ηeff = Certified efficiency of new stove. Use actual or assume defaults below.[[343]](#footnote-343)

|  |  |
| --- | --- |
| Stove Type | Efficiency (ηeff) |
| Pellet | 77% |
| Cordwood | 75% |

0.00106 = MJ per BTU

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

CI = Carbon intensity of fuel [g CO2e/MJ]. See Table x in Reference Section.

CI’ = Carbon intensity adder for delivery of fuel to end user. See Table z in Reference Section.

#### Measure Life

The expected measure life is 18 years.[[344]](#footnote-344)

#### 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 |
| Cordwood | $2,475 | $383 | $469 | $3,319 |

\*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 (ηeff)

For additional accuracy, the following variable should also be tracked:

* 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)[[345]](#footnote-345) 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>).

### Air Source Heat Pump – Ducted, Full Displacement

**CHS Measure ID:** RE\_HVAC\_HPDF

**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:

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 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 ≥ 14.3, HSPF2 ≥ 7.7, COP at 5°F ≥ 1.75 at maximum capacity operation)[[346]](#footnote-346)
* 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 102 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 102. Example Residential ASHP-Ducted-Full Displacement CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Building Type | Baseline Heating Fuel | Lifetime CO2e Reductions per TonR [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Single Family | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Multifamily | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Unknown | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 103)[[347]](#footnote-347)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 103)[[348]](#footnote-348)

Table 103. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency (ηave,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 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / HSPF2 x 3.412) x CIelec / (1 – TDLelec)

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh] = 7.7.

3.412 = Btu per Watt-hour. Used to convert HSPF2 [Btu/(Watt hour)] to COP [dimensionless). COP = HSPF2/3.412.

Ehl = Heating load served by the heat pump [MJ] = (HCAP47F x EFLHheat) x 0.00106

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,909 hours.[[349]](#footnote-349)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/SEER2) x 0.0036

%Cool = Percent of Vermont existing homes with central cooling.[[350]](#footnote-350)

|  |  |
| --- | --- |
| Central Cooling? | %Cool |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 15% |
| Unknown, Multifamily | 12% |
| Unknown, Building Type Unknown | 14.70% |

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.

EFLHcool = Equivalent full load cooling hours = 240 hours.[[351]](#footnote-351)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 16 years.[[352]](#footnote-352)

#### Measure Cost

The assumed full retrofit cost of ducted air source heat pumps is below[[353]](#footnote-353):

|  |  |
| --- | --- |
| 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 |

#### Program Data Tracking Recommendations

The key input variables for this measure are the following:

* Rated heating capacity at 47°F of heat pump (HCAP47F).
* 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.

### 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 ≥ 15.2, EER2 ≥ 11.7, HSPF2 ≥ 7.8)[[354]](#footnote-354).
* 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 104 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 104. Example Residential ASHP-Ducted-Partial Displacement CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Building Type | Baseline Heating Fuel | Lifetime CO2e Reductions per TonR  [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR  [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Single Family | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Multifamily | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Unknown | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 105)[[355]](#footnote-355)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 105)[[356]](#footnote-356)

Table 105. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency (ηave,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 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / HSPF2 x 3.412) x CIelec / (1 – TDLelec)

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh] = 7.8.

3.412 = Btu per Watt-hour. Used to convert HSPF2 [Btu/(Watt hour)] to COP [dimensionless). COP = HSPF2/3.412.

Ehl = Heating load served by the heat pump [MJ] = (HF x HCAP47F x EFLHheat) x 0.00106

HF = Heatload Factor, reduces EFLH to account for partial displacement. = 34%.[[357]](#footnote-357)

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,909 hours.[[358]](#footnote-358)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/SEER2) x 0.0036

%Cool = Percent of Vermont existing homes with central cooling.[[359]](#footnote-359)

|  |  |
| --- | --- |
| Central Cooling? | %Cool |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 15% |
| Unknown, Multifamily | 12% |
| Unknown, Building Type Unknown | 14.70% |

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.

EFLHcool = Equivalent full load cooling hours = 240 hours.[[360]](#footnote-360)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 16 years.[[361]](#footnote-361)

#### Measure Cost

The assumed full retrofit cost of ducted air source heat pumps is below[[362]](#footnote-362):

|  |  |
| --- | --- |
| 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 |

#### Program Data Tracking Recommendations

The key input variables for this measure are the following:

* Rated heating capacity at 47°F of heat pump (HCAP47F).
* 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.

### 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 ≥ 15, HSPF2 ≥ 8.5. COP at 5°F ≥ 1.75 at maximum capacity operation)[[363]](#footnote-363)
* 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 106 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 106. Example Residential ASHP-Ductless-Full Displacement CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Building Type | Baseline Heating Fuel | Lifetime CO2e Reductions per TonR [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Single Family | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Multifamily | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Unknown | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 107)[[364]](#footnote-364)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 107)[[365]](#footnote-365)

Table 107. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency (ηave,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 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / HSPF2 x 3.412) x CIelec / (1 – TDLelec)

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh] = 8.5.

3.412 = Btu per Watt-hour. Used to convert HSPF2 [Btu/(Watt hour)] to COP [dimensionless). COP = HSPF2/3.412.

Ehl = Heating load served by the heat pump [MJ] = (HCAP47F x EFLHheat) x 0.00106

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,909 hours.[[366]](#footnote-366)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/SEER2) x 0.0036

%Cool = Percent of Vermont existing homes with central cooling.[[367]](#footnote-367)

|  |  |
| --- | --- |
| Central Cooling? | %Cool |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 15% |
| Unknown, Multifamily | 12% |
| Unknown, Building Type Unknown | 14.70% |

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.

EFLHcool = Equivalent full load cooling hours = 240 hours.[[368]](#footnote-368)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 16 years.[[369]](#footnote-369)

#### Measure Cost

The assumed full retrofit cost of ductless air source heat pumps is below[[370]](#footnote-370):

|  |  |  |  |
| --- | --- | --- | --- |
| 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:

* Rated heating capacity at 47°F of heat pump (HCAP47F).
* 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.

### 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 ≥ 15.2, EER2 ≥ 11.7, HSPF2 ≥ 7.8)[[371]](#footnote-371)
* 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 108 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 108. Example Residential ASHP-Ductless-Partial Displacement CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Building Type | Baseline Heating Fuel | Lifetime CO2e Reductions per TonR  [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR  [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Single Family | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Multifamily | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Unknown | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 109)[[372]](#footnote-372)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 109)[[373]](#footnote-373)

Table 109. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

| Heating Fuel | Building Type | | | Average Existing Heating Efficiency (ηave,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 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / HSPF2 x 3.412) x CIelec / (1 – TDLelec)

HSPF2 = Heating Season Performance Factor2 (HSPF2) rating for heat pump (heating efficiency) [Btu/Wh] = 7.8.

3.412 = Btu per Watt-hour. Used to convert HSPF2 [Btu/(Watt hour)] to COP [dimensionless). COP = HSPF2/3.412.

Ehl = Heating load served by the heat pump [MJ] = (HF x HCAP47F x EFLHheat) x 0.00106

HF = Heatload Factor, reduces EFLH to account for partial displacement. = 34%.[[374]](#footnote-374)

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,909 hours.[[375]](#footnote-375)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/SEER2) x 0.0036

%Cool = Percent of Vermont existing homes with central cooling.[[376]](#footnote-376)

|  |  |
| --- | --- |
| Central Cooling? | %Cool |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 15% |
| Unknown, Multifamily | 12% |
| Unknown, Building Type Unknown | 14.70% |

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.

EFLHcool = Equivalent full load cooling hours = 240 hours.[[377]](#footnote-377)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 16 years.[[378]](#footnote-378)

#### Measure Cost

The assumed full retrofit cost of ductless air source heat pumps is below[[379]](#footnote-379):

|  |  |  |  |
| --- | --- | --- | --- |
| 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:

* Rated heating capacity at 47°F of heat pump (HCAP47F).
* 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.

### 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 110 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 COPheat = 2.83

Table 110. Example Residential ASHP-Ducted-Full Displacement CO2e Reductions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Building Type | Baseline heating fuel | Lifetime CO2e Reductions per TonR  [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR  [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Single Family | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Multifamily | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Unknown | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 111)[[380]](#footnote-380)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 111)[[381]](#footnote-381)

Table 111. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Heating Fuel | Building Type | | | Average Existing Heating Efficiency (ηave,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 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / COPhp) x CIelec / (1 – TDLelec)

COPhp = Coefficient of Performance (COP) rating for heat pump (heating efficiency) [dimensionless]. Use average COP over operating conditions or refer to Table 112 if unknown.

Table 112. Default AWHP Heating Efficiency

| Rated Heating Capacity [tonsR] | COPhp[[382]](#footnote-382) |
| --- | --- |
| 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 |

Ehl = Heating load served by the heat pump [MJ] = (HCAP47F x EFLHheat) x 0.00106

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,909 hours.[[383]](#footnote-383)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be comparable to an air-to-air heat pump: 16 years.[[384]](#footnote-384)

#### 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.[[385]](#footnote-385) 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  [tonsR] | Retrofit Cost[[386]](#footnote-386) |
| 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

### 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:[[387]](#footnote-387)

|  |  |  |
| --- | --- | --- |
| Efficiency Level | HRV | ERV |
| Tier 1 | SRE 70% or above | SRE 70% or above |
| Tier 2 | SRE 80% or above | SRE 80% or above |

#### 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.[[388]](#footnote-388)

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 113 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 114.
* Default HRV/ERV size for unknown building type per Table 118.

Table 113. Example ERV and HRV CO2e Reductions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Unit Type | Proposed Efficiency Level | Heating Fuel | Lifetime CO2e Reductions, Thermal [g] | Lifetime CO2e Reductions, Total [g] | Lifetime Credits |
| ERV | Tier 1 | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electric |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |
| Tier 2 | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electric |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |
| HRV | Tier 1 | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electric |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |
| Tier 2 | Oil |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Electric |  |  |  |
| Wood |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Total annual carbon dioxide equivalent emissions reductions in grams [g] = ΔCO2eheat

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = CO2e emissions reductions from reducing heating energy

If heating fuel is known:

Oil: ΔCO2eheat = (ΔEhl/ ηave,oil) x (CIoil + CI’oil)

Propane: ΔCO2eheat = (ΔEhl/ ηave,LP) x (CILP + CI’LP)

Natural gas: ΔCO2eheat = (ΔEhl/ηave,NG x CING) / (1 – TDLNG)

Electricity: ΔCO2eheat = (ΔEhl/ηave,elec x CING) / (1 – TDLelec)

Wood: ΔCO2eheat = (ΔEhl/ ηave,wood) x (CIwood + CI’wood)

If heating fuel is unknown:

ΔCO2eheat = (%Oil x ΔEhl/ ηave,oil x (CIoil+CI’oil)) + (%LP x ΔEhl/ ηave,LP x (CILP+CI’LP)) + (%NG x ΔEhl/ηave,NG x CING)/(1-TDLNG) + (%Elec x ΔEhl/ηave,elec x CIelec)/(1-TDLelec) + (%Wood x ΔEhl/ηave,wood x (CIwood+ CI’wood))

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 114)[[389]](#footnote-389)

Table 114. Vermont Primary Heating Fuel Mix and Average Efficiency, Residential Buildings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Heating Fuel | Building Type | | | Average Existing Heating Efficiency (ηave,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 |

ΔEhl = Reduction in heating load [MJ] = (1.08 x CFMave x HDH x (ASREEE – ASREBase)) x 0.00106

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

HDH = Heating Degree Hours [°F hr] = 129,936 [[390]](#footnote-390)

ASREBase= Adjusted Sensible Recovery Efficiency of the baseline ERV or HRV; see Table 119.[[391]](#footnote-391)

ASREEE = Adjusted Sensible Recovery Efficiency of the efficient ERV or HRV; see Table 119.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2ecool = CO2e emissions reductions [g] from reducing cooling energy = (ΔEcl/ηcool x CIelec)/(1-TDLelec)

ΔEcl = Reduction in cooling load [MJ] = (%Cool x 4.5 x CFMave x ΔH x (ATREEE – ATREBase)) x 0.00106

%Cool = Percent of Vermont homes with central cooling[[392]](#footnote-392)

| Central Cooling? | %Cool | |
| --- | --- | --- |
|  | Early Replacement | New Construction |
| Yes | 100% | |
| No | 0% | |
| Unknown, Single Family | 15% | 41% |
| Unknown, Multifamily | 12% | 41% |
| Unknown, Unknown Building Type | 14.7% | 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 [[393]](#footnote-393)

ATREBase= Adjusted Total Recovery Efficiency of the baseline ERV or HRV; see Table 119.

ATREEE = Adjusted Total Recovery Efficiency of the efficient ERV or HRV; see Table 119.

ηcool = Cooling system efficiency = 5.72.[[394]](#footnote-394)

ΔCO2efan = CO2e emissions reductions [g] from reducing fan energy = (ΔEfan x CIelec)/(1-TDLelec)

ΔEfan = Reduction in ERV/HRV fan energy = ((WattsAve,Base – WattsAve,EE) x 8760) x 0.0036

WattsAve,Base = Average operating wattage of baseline HRV/ERV; see Table 115 if size is known or refer to Table 116.

WattsAve,EE = Average operating wattage of high efficiency ERV/HRV; see Table 115 if size is known or refer to Table 116.

Table 115. ERV/HRV Average Wattages by Unit Size

| Unit Type | Size [CFM] | Baseline | Tier 1 | Tier 2 |
| --- | --- | --- | --- | --- |
| WattsAve,Base | WattsAve,EE | WattsAve,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 |
| 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 116. ERV/HRV Default Wattages by Building type

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Unit Type | Building Type | Average Size | Baseline | Tier 1 | Tier 2 |
| CFMave | WattsAve,Base | WattsAve,EE | WattsAve,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**

CFMave = Average volumetric flow of supply air [CFM] to the ERV. Select based on Table 117 if size is known, or use defaults from Table 118.[[395]](#footnote-395)

Table 117. Residential HRV/ERV: Assumed Average Operating Supply Airflow by Unit Size

|  |  |
| --- | --- |
| Size [CFM] | Assumed Average Supply Airflow (CFMave) |
| 30 - 79 | 53 |
| 80 – 129 | 60 |
| 130 – 179 | 72 |
| 180 – 229 | 85 |
| 230+ | 115 |

Table 118. Residential ERV/HRV: Default Supply Air Volumetric Flow (CFM) by Building type

|  |  |  |
| --- | --- | --- |
| Building Type | Average Size [CFM] | Assumed Average Supply Airflow (CFMave) |
| Single Family | 114 | 60 |
| Multifamily | 64 | 53 |
| Unknown | 99 | 60 |

Table 119. ERV/HRV Adjusted Sensible and Total Recovery Efficiency (ASRE/ATRE)

|  |  |  |  |
| --- | --- | --- | --- |
| 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 x in Reference Section)

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life of installed equipment is estimated to be 15 years. [[396]](#footnote-396)

#### Measure Cost

The incremental measure costs for installing Tier 1 or Tier 2 equipment are presented in Table 120.[[397]](#footnote-397)

Table 120. ERV/HRV Measure Cost

|  |  |  |
| --- | --- | --- |
| Efficiency Category | ERV | HRV |
| Tier 1 | $141.00 | $154.00 |
| Tier 2 | $552.00 | $345.00 |

#### 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 (ASREEE)
* ERV/HRV Adjusted Total Heat Recovery (ATREEE)

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.[[398]](#footnote-398)

### 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:[[399]](#footnote-399)

Table 121. 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 122 provides estimated lifecycle decarbonization ranges on a per ton of refrigeration basis (1 tonR = 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 central A/C presence is unknown

Table 122. Example Residential GSHP Lifetime CO2e Reductions per TonR

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| GSHP Type | Baseline Heating Fuel | Lifetime CO2e Reductions per TonR  [g CO2e/tonR], Thermal Sector | Lifetime CO2e Reductions per TonR  [g CO2e/tonR],  Total | Lifetime Credits  per TonR |
| Water-to-Air, Closed Loop | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Water-to-Air, Open Loop | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Water-to-Water, Closed Loop | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| Water-to-Water, Open Loop | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| DGX-to-Air | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |
| DGX-to-Water | Natural Gas |  |  |  |
| Propane |  |  |  |
| Fuel Oil #2 |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase – CO2eHPheat

CO2ebase = Annual CO2e emissions [g] from baseline heating system

If baseline fuel is known:

Oil: CO2ebase = (Ehl/ ηave,oil) x (CIoil + CI’oil)

Propane: CO2ebase = (Ehl/ ηave,LP) x (CILP + CI’LP)

Natural gas: CO2ebase = (Ehl/ηave,NG x CING) / (1 – TDLNG)

If baseline heating fuel is unknown:

CO2ebase = ((%Oil x Ehl x (CIoil+CI’oil))/ηave,oil) + ((%LP x Ehl x (CILP+CI’LP)) /ηave,LP) + ((%NG x Ehl x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Ehl x CIelec) /ηave,elec)/(1-TDLelec) + ((%Wood x Ehl x (CIwood+ CI’wood)) /ηave,wood)

%Oil, etc. = Relative proportion of fuel in Vermont’s primary heating fuel mix (see Table 123)[[400]](#footnote-400)

ηave,fuel = Average heating efficiency by fuel type [dimensionless] (see Table 123)[[401]](#footnote-401)

Table 123. Vermont Primary Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

|  |  |  |
| --- | --- | --- |
| Heating Fuel | Building Type | Average Existing Heating Efficiency (ηave,fuel) |
| Single Family %Fuel |
| Oil | 45% | 0.84 |
| Propane (LP) | 17% | 0.85 |
| Natural Gas (NG) | 23% | 0.84 |
| Electricity | 6% | 2.52 |
| Wood | 8% | 0.67 |

CO2eHPheat =Annual CO2e emissions [g] due to heat pump heating operation =

(Ehl / COP) x CIelec / (1 – TDLelec)

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 52).

Ehl = Heating load served by the heat pump [MJ] = (HCAP47F x EFLHheat) x 0.00106

HCAP47F = Rated heating output capacity of heat pump at 47°F in Btu’s per hour [Btu/h]

EFLHheat = Equivalent full load heating hours = 1,909 hours.[[402]](#footnote-402)

0.00106 = MJ per Btu.

**Non-Thermal Sector CO2e Impacts:**

ΔCO2eHPcool =CO2e emissions impact [g] due to added cooling load = (ΔEcool x CIelec) / (1–TDLelec)

ΔEcool = Cooling energy impacts [MJ] = –((1 - %Cool) x (CCAP x EFLHcool)/EER) x 0.0036

%Cool = Percent of Vermont existing homes with central cooling.[[403]](#footnote-403)

|  |  |
| --- | --- |
| Central Cooling? | %Cool |
| Yes | 100% |
| No | 0% |
| Unknown, Single Family | 15% |

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 52).

EFLHcool = Equivalent full load cooling hours = 240 hours.[[404]](#footnote-404)

0.0036 = MJ per Watt-hour.

**Common Inputs**

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### 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.[[405]](#footnote-405)

#### 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.[[406]](#footnote-406)

#### 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

#### Energy Codes and Standards

ENERGY STAR® Program Requirements Product Specification for Geothermal Heat Pumps: Eligibility Criteria Version 3.2.

## Miscellaneous

### 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:** 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.[[407]](#footnote-407)

**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.

#### 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 124 provides lifecycle CO2e reductions for single and double wide efficient and electric manufactured homes.

Assumptions:

* Baseline and proposed conditions described above

Table 124. Efficient and Electric Manufactured Home CO2e Reduction Summary

|  |  |  |  |
| --- | --- | --- | --- |
| Manufactured Home Size | Lifetime CO2e Reductions [g], Thermal Sector | Lifetime CO2e Reductions [g],  Total | Lifetime Credits |
| Single |  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
| Double |  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

#### Decarbonization and Energy impacts Algorithms

**Thermal Sector Decarbonization Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2eheat + ΔCO2eDHW +ΔCO2eother

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton

ΔCO2eheat = CO2e emissions reductions for space heating = ΔCO2eheat,base + ΔCO2eheat,elec

ΔCO2eheat,base = (ΔEheat,LP x (CILP + CI’LP)) + (ΔEheat,oil x (CIoil + CI’oil))

ΔCO2eheat,elec = (ΔEheat,elec x CIelec)/(1 – TDLelec)

ΔCO2eDHW = CO2e emissions reductions for domestic hot water = ΔCO2eDHW,base + ΔCO2eDHW,elec

ΔCO2eDHW,base = ΔEDHW,LP x (CILP + CI’LP)

ΔCO2eDHW,elec = (ΔEDHW,elec x CIelec)/(1 – TDLelec)

ΔCO2eother = CO2e emissions reductions for other end uses (mostly clothes drying) = ΔEother x CIelec

**Non-Thermal Sector Decarbonization Impacts:**

ΔCO2ecool = CO2e emissions impacts for space cooling = ΔEcool x CIelec

**Common Inputs**

Energy savings in megajoules [MJ] are prescribed for each end use according to the following:[[408]](#footnote-408)

| End Use | Variable Name | Single Wide – Savings [MJ] | | | Double Wide – Savings [MJ] | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Electric | Propane | Oil | Electric | Propane | Oil |
| Space Heating | ΔEheat,fuel | -10,619.6 | 40,725.2 | 10,128.5 | -9,486.7 | 38,193.0 | 9,495.5 |
| Space Cooling | ΔEcool | 1,420.2 |  |  | 1,386.4 |  |  |
| Water Heating | ΔEDHW,fuel | 239.8 | 12,238.6 |  | -1,959.1 | 17,513.9 |  |
| Other | ΔEOther | 695.9 |  |  | 780.1 |  |  |

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### 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:

* 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)[[409]](#footnote-409)

ENERGY STAR Manufactured New Homes National Program Requirements, Version 3[[410]](#footnote-410)

US Department of Energy Zero Energy Ready Home Manufactured Home (ZERH MH), Version 1[[411]](#footnote-411)

### 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 125 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 126
* 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 125. 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 |  |  |  |
| Propane |  |  |  |
| Natural Gas |  |  |  |
| Unknown |  |  |  |

#### Decarbonization and Energy Impacts Algorithms

**Thermal Sector CO2e Reductions:**

ΔCO2ethermal = Annual thermal sector CO2e reductions in grams [g] = ΔCO2edirect

Annual Clean Heat Credits = ΔCO2ethermal / 1,000,000 x CreditValue

CreditValue = 1 credit/tonCO2e

1,000,000 = Grams per metric ton.

ΔCO2edirect = Annual CO2e reduction [g] due to equipment replacement = CO2ebase - CO2eHP

CO2ebase = Annual CO2e emissions [g] from baseline pool water heater

If baseline fuel is known:

Oil: CO2ebase = Eload / ηave,oil x (CIoil + CI’oil)

Propane: CO2ebase = Eload / ηave,LP x (CILP + CI’LP)

Natural Gas: CO2ebase = (Eload / ηave,NG x CING) / (1 – TDLNG)

If baseline fuel is unknown:

CO2ebase = ((%Oil x Eload x (CIoil+CI’oil))/ηave,oil) + ((%LP x Eload x (CILP+CI’LP)) /ηave,LP) + ((%NG x Eload x CING) /ηave,NG)/(1-TDLNG) + ((%Elec x Eload x CIelec) /ηave,elec)/(1-TDLelec)

%Oil, etc. = Relative proportion of fuel in Vermont’s water heating fuel mix (see Table 33). Pool water heating fuel mix is assumed to approximate domestic hot water fuel mix.[[412]](#footnote-412)

ηave,fuel = Assumed average pool water heater efficiency by fuel (see Table 126)[[413]](#footnote-413)

Table 126. Vermont Water Heating Fuel Mix and Average Heating Efficiency, Residential Buildings

|  |  |  |
| --- | --- | --- |
| Pool Water Heating Fuel | Fuel Mix | Average Efficiency (ηave,fuel) |
| Oil | 9% | 0.85 |
| Propane (LP) | 24% | 0.85 |
| Natural Gas | 23% | 0.85 |
| Electricity | 43% | 0.99 |

CO2eHP = CO2e emissions from heat pump pool water heater [g] = (Eload / COPHP x CIelec) / (1 – TDLelec)

COPHP = Coefficient of performance (COP) of proposed heat pump pool water heater [dimensionless]. Use actual or assume 4.79 if unknown.[[414]](#footnote-414)

**Non-Thermal Sector CO2e Impacts:** None

**Common Inputs**

Eload = Annual pool water heating load [MJ] =

= (MMBTUsurface + MMBTUreheat + MMBTUevap - MMBTUsolar) x 1,055

MMBTUsurface = 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 (no pool cover)

= 141.18 (pool covered from 8pm to 8am)

= 155.82 (pool cover use unknown) [[415]](#footnote-415)

MMBTUreheat = 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°F[[416]](#footnote-416) to 82°F

= 5.87

MMBTUevap = 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 (no pool cover)

= 2.13 (pool covered from 8pm to 8am)

= 2.14 (pool cover use unknown)

MMBTUsolar = Annual solar heat gain. Based on Global Horizontal Incidence modified to account for cloud cover and a solar absorptance factor of 0.77.[[417]](#footnote-417)

= 57.08 (with or without pool cover)

1,055 = MJ per MMBTU

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

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

TDL = Transmission and distribution losses (see Table y in Reference Section)

#### Measure Life

The expected measure life is assumed to be 5 years.[[418]](#footnote-418)

#### Measure Cost

The retrofit cost of a heat pump pool water heater is $4,200.[[419]](#footnote-419)

#### Program Data Tracking Recommendations

The following variables should be tracked for this measure:

* Fuel type and efficiency of existing pool heater (ηbase)
* COP of proposed heat pump water heater (COPhp)
* Use of pool cover and estimated hours of use

#### Energy Codes and Standards

Minimum efficiencies for pool heaters are prescribed in federal standard 10 CFR 430.32(k)(2).

# Fuel Measures

1. 30 V.S.A. § 8126(c). [↑](#footnote-ref-1)
2. Additional definition not from 30 V.S.A. § 8123. [↑](#footnote-ref-2)
3. 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> [↑](#footnote-ref-3)
4. Definition sourced from 10 V.S.A. § 2681(a)(3). [↑](#footnote-ref-4)
5. 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. [↑](#footnote-ref-5)
6. 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”. [↑](#footnote-ref-6)
7. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer , page 178, footnote 12 [↑](#footnote-ref-7)
8. 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.” [↑](#footnote-ref-8)
9. Ibid. [↑](#footnote-ref-9)
10. 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.” [↑](#footnote-ref-10)
11. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-11)
12. 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). [↑](#footnote-ref-12)
13. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer , page 179, footnote 14 [↑](#footnote-ref-13)
14. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 176, footnote 2 [↑](#footnote-ref-14)
15. 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. [↑](#footnote-ref-15)
16. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 178, footnote 13 [↑](#footnote-ref-16)
17. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England [↑](#footnote-ref-17)
18. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. Source reference not provided. [↑](#footnote-ref-18)
19. 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. [↑](#footnote-ref-19)
20. 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>” [↑](#footnote-ref-20)
21. US Energy Information Administration, Commercial Buildings Energy Consumption Survey, 2018. Table B11. [↑](#footnote-ref-21)
22. Illinois TRM v12, C/I Efficient Cooktops. Source: Frontier Energy, Inc. 2023. “Cooktop\_Supporting\_Data\_R2 2023-07-30.xlsx”. [↑](#footnote-ref-22)
23. Ibid. [↑](#footnote-ref-23)
24. Ibid. [↑](#footnote-ref-24)
25. Ibid. [↑](#footnote-ref-25)
26. Ibid. [↑](#footnote-ref-26)
27. 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” [↑](#footnote-ref-27)
28. 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. [↑](#footnote-ref-28)
29. Weighted-average of electric, natural gas, and propane incremental costs using unknown building type mix in Table 2. [↑](#footnote-ref-29)
30. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-30)
31. 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). [↑](#footnote-ref-31)
32. 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.” [↑](#footnote-ref-32)
33. 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 Internation 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.” [↑](#footnote-ref-33)
34. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England [↑](#footnote-ref-34)
35. Energy Center of Wisconsin, *Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research,* 2008, page 31. [↑](#footnote-ref-35)
36. *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.” [↑](#footnote-ref-36)
37. 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. [↑](#footnote-ref-37)
38. Illinois TRM v12.0. “Fe 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 (Ef in MMBTU/yr) and Eae (kWh/yr). An average of a 300 record sample (non-random) out of 1495 was 3.14%.” [↑](#footnote-ref-38)
39. 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. [↑](#footnote-ref-39)
40. Illinois TRM v12.0. As recommended in Navigant ‘ComEd Effective Useful Life Research Report’, May 2018. [↑](#footnote-ref-40)
41. Efficiency Vermont TRM Program Year 2023, HPwES 2.0 Airsealing. No reference given. [↑](#footnote-ref-41)
42. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-42)
43. 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). [↑](#footnote-ref-43)
44. 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. [↑](#footnote-ref-44)
45. *Efficiency Vermont TRM Program Year 2023,* HPwES 2.0 Insulation: Attic and/or Basement, page 302, footnote 5*.*  [↑](#footnote-ref-45)
46. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England [↑](#footnote-ref-46)
47. Energy Center of Wisconsin, *Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research,* 2008, page 31. [↑](#footnote-ref-47)
48. *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.” [↑](#footnote-ref-48)
49. 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. [↑](#footnote-ref-49)
50. Illinois TRM v12.0. “Fe 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 (Ef in MMBTU/yr) and Eae (kWh/yr). An average of a 300 record sample (non-random) out of 1495 was 3.14%.” [↑](#footnote-ref-50)
51. Insulation tables are derived from ASHRAE 90.1-2016 Normative Appendix A. [↑](#footnote-ref-51)
52. *Efficiency Vermont TRM Program Year 2023,* HPwES 2.0 Insulation: Attic and/or Basement, HPwES 2.0 Insulation: Exterior Walls. [↑](#footnote-ref-52)
53. Ibid. [↑](#footnote-ref-53)
54. NEEA Advanced Water Heating Specification 8.1, <https://neea.org/img/documents/Advanced-Water-Heating-Specification.pdf>. [↑](#footnote-ref-54)
55. Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70. [↑](#footnote-ref-55)
56. 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. [↑](#footnote-ref-56)
57. Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70. [↑](#footnote-ref-57)
58. 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. [↑](#footnote-ref-58)
59. 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-neea-spec-2021.xlsx.” [↑](#footnote-ref-59)
60. 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. [↑](#footnote-ref-60)
61. 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"” [↑](#footnote-ref-61)
62. Derived from US Energy Information Administration Commercial Buildings Energy Consumption Survey (CBECS) 2018, Table B21, New England. [↑](#footnote-ref-62)
63. New York TRM v11. “Per OSHA recommendations for prevention of Legionella bacterial growth. (<https://www.osha.gov/SLTC/legionnairesdisease/control_prevention.html>)” [↑](#footnote-ref-63)
64. 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 [↑](#footnote-ref-64)
65. New York TRM v11, C/I Storage Tank Water Heater. [↑](#footnote-ref-65)
66. 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. [↑](#footnote-ref-66)
67. National Renewable Energy Laboratory, Saving Energy in Commercial Buildings: Domestic Hot Water Assessment Guidelines, Table 1. Hot Water Use By Building Type, June 2011. [↑](#footnote-ref-67)
68. Water Research Foundation: Residential End Uses of Water, Version 2, April 2016. [↑](#footnote-ref-68)
69. Food Service Technology Center, Design Guide – Energy Efficient Heating, Delivery and Use, Table 1. Typical hot water system cost for restaurants, March 2010. [↑](#footnote-ref-69)
70. Residential Statewide Baseline Study of New York State, July 2015. Volume 2: Multifamily Report, Table 8. [↑](#footnote-ref-70)
71. 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?gId=6&ctId=270>” [↑](#footnote-ref-71)
72. Existing faucets are assumed to comply with the federal standard which is 2.2 GPM at 60 psi. 10 CFR § 430.32. [↑](#footnote-ref-72)
73. 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. [↑](#footnote-ref-73)
74. Efficiency Vermont Technical Reference Manual. 2023. Average flow rate of products on the WaterSense Labeled Products list as of October 18, 2022. [↑](#footnote-ref-74)
75. Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70. [↑](#footnote-ref-75)
76. Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 5, 6, 18, and 19. [↑](#footnote-ref-76)
77. 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. [↑](#footnote-ref-77)
78. Ibid. [↑](#footnote-ref-78)
79. FEMP, Domestic Water Conservation Technologies, p. 35. [↑](#footnote-ref-79)
80. California Energy Commission, Characterizing the Energy Efficiency Potential of Gas-Fired Commercial Foodservice Equipment, Appendix E. [↑](#footnote-ref-80)
81. The Unknown building type value is equal to the average of the known building type values. [↑](#footnote-ref-81)
82. Ibid. [↑](#footnote-ref-82)
83. 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 [↑](#footnote-ref-83)
84. Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 12, 13. [↑](#footnote-ref-84)
85. Efficiency Vermont Technical Reference Manual. 2023. Measure lifetime from California DEER. See file DEER2014-EUL-table-update\_2014-02-05.xlsx. [↑](#footnote-ref-85)
86. Efficiency Vermont Technical Reference Manual. 2023. See footnotes 21-23. [↑](#footnote-ref-86)
87. “Vermont 2018”. Appliance Standards Awareness Project, https://appliance-standards.org/state-legislation/vermont-2018. [↑](#footnote-ref-87)
88. Existing showerheads are assumed to comply with the federal standard which is 2.5 GPM at 80 psi. 10 CFR § 430.32 [↑](#footnote-ref-88)
89. 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. [↑](#footnote-ref-89)
90. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnote 10 [↑](#footnote-ref-90)
91. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnote 11 [↑](#footnote-ref-91)
92. Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70. [↑](#footnote-ref-92)
93. Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 5, 6, 18, and 19. [↑](#footnote-ref-93)
94. Cadmus and Opinion Dynamics, for the Michigan Evaluation Working Group, "Showerhead and Faucet Aerator Meter Study Memorandum," June 2013, page 11, Table 7. [↑](#footnote-ref-94)
95. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 16 [↑](#footnote-ref-95)
96. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 17 [↑](#footnote-ref-96)
97. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnotes 12, 13. [↑](#footnote-ref-97)
98. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 21 [↑](#footnote-ref-98)
99. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 198. See footnotes 22 – 25. [↑](#footnote-ref-99)
100. “Vermont 2018”. Appliance Standards Awareness Project, https://appliance-standards.org/state-legislation/vermont-2018. [↑](#footnote-ref-100)
101. See <https://solar-rating.org> for certified product list. [↑](#footnote-ref-101)
102. Cadmus 2023, 2021 Vermont Business Sector Market Characterization Study, Figure 70. [↑](#footnote-ref-102)
103. 10 CFR 431.110(a). Table 1: Commercial Water Heater Energy Conservation Standards. [↑](#footnote-ref-103)
104. New York TRM v11. “Per OSHA recommendations for prevention of Legionella bacterial growth. (<https://www.osha.gov/SLTC/legionnairesdisease/control_prevention.html>)” [↑](#footnote-ref-104)
105. 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 [↑](#footnote-ref-105)
106. Table 6 is from New York TRM v11, C/I Storage Tank Water Heater. [↑](#footnote-ref-106)
107. 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. [↑](#footnote-ref-107)
108. National Renewable Energy Laboratory, Saving Energy in Commercial Buildings: Domestic Hot Water Assessment Guidelines, Table 1. Hot Water Use By Building Type, June 2011. [↑](#footnote-ref-108)
109. Water Research Foundation: Residential End Uses of Water, Version 2, April 2016. [↑](#footnote-ref-109)
110. Food Service Technology Center, Design Guide – Energy Efficient Heating, Delivery and Use, Table 1. Typical hot water system cost for restaurants, March 2010. [↑](#footnote-ref-110)
111. Residential Statewide Baseline Study of New York State, July 2015. Volume 2: Multifamily Report, Table 8. [↑](#footnote-ref-111)
112. Act 56 Tier III Planning Tool PY2024\_2\_13\_2024.xlsx. [↑](#footnote-ref-112)
113. 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. [↑](#footnote-ref-113)
114. 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. [↑](#footnote-ref-114)
115. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats. [↑](#footnote-ref-115)
116. Ibid. [↑](#footnote-ref-116)
117. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-117)
118. 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.” [↑](#footnote-ref-118)
119. Derived from NMR Group, *2020 Vermont Single Family Existing Homes Baseline Study*. The mean HSPF of Heat Pump Systems is 11.2. [↑](#footnote-ref-119)
120. Efficiency Vermont TRM Program Year 2023, Central Wood Pellet Boilers and Furnaces. “Efficiency of existing wood heating systems based on professional judgment.” [↑](#footnote-ref-120)
121. Calculated using assumptions from Efficiency Vermont TRM Program Year 2023, Advanced Thermostats (Capacity = Gas Heating Consumption × 1,000,000/EFLHheat). [↑](#footnote-ref-121)
122. Calculated using assumptions from Efficiency Vermont TRM Program Year 2023, Advanced Thermostats (Capacity = Electric Heating Consumption × 3412/EFLHheat  × %Controlled × COP). [↑](#footnote-ref-122)
123. Source: Tables 50 and 137, Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study. [↑](#footnote-ref-123)
124. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 152, footnote 10 [↑](#footnote-ref-124)
125. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England. [↑](#footnote-ref-125)
126. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 206, footnote 3 [↑](#footnote-ref-126)
127. 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 [↑](#footnote-ref-127)
128. 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. [↑](#footnote-ref-128)
129. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 154, footnote 15 [↑](#footnote-ref-129)
130. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 153, footnote 11 [↑](#footnote-ref-130)
131. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 207 [↑](#footnote-ref-131)
132. Ibid. [↑](#footnote-ref-132)
133. 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.” [↑](#footnote-ref-133)
134. Efficiency Vermont 2023 TRM. “Efficiency of new wood heating systems based on professional judgment.” [↑](#footnote-ref-134)
135. Efficiency Vermont 2023 TRM. “Efficiency of existing wood heating systems based on professional judgment.” [↑](#footnote-ref-135)
136. Efficiency Vermont 2023 TRM. “Commercial FLH is a weighted average of commercial FLH values from New York Joint Utiliites,"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.” [↑](#footnote-ref-136)
137. Efficiency Vermont 2023 TRM. “Efficiency of new wood heating systems based on professional judgment.” [↑](#footnote-ref-137)
138. Efficiency Vermont 2023 TRM. “Efficiency of existing wood heating systems based on professional judgment.” [↑](#footnote-ref-138)
139. 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.” [↑](#footnote-ref-139)
140. 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. [↑](#footnote-ref-140)
141. Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers & Furnaces. “The baseline full installation cost for commercial NC is based on data from Cadmus, "2016 Vermont Business Sector Market Characterization and Assessment Study," April 30, 2017: page 178, Figure 129 ("All" data) and page 181, Figure 131. Boilers are divided between propane (44%) and wood (14%), and it is assumed that all furnaces are propane-fired. Full installation costs for baseline heating systems, except for cordwood boilers, are the average of typical residential costs for years 2013 and 2020 from U.S. EIA, "Updated Buildings Sector Appliance and Equipment Costs and Efficiencies," November 2016. Cordwood boilers are assumed to cost the same as pellet boilers ($20,000). See EVT\_Central Wood Pellet Boilers and Furnaces\_Analysis\_Jan 2018.xlsx for measure cost calculations.” [↑](#footnote-ref-141)
142. 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.” [↑](#footnote-ref-142)
143. 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. [↑](#footnote-ref-143)
144. 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 pelelts 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.” [↑](#footnote-ref-144)
145. 2023 Vermont Tier III TRM. “%stove for wood stoves is calculating using: the percentage of primary (53%) versus supplemental (47%) cordwood users in Vermont and the annual number of cords burned by primary (4.8) versus supplemental (2.1) cordwood users from Vermont Department of Forests, Parks, and Recreation, "Vermont Residential Fuel Assessment for the 2014-2015 Heating Season," March 2016, page 6; 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); 68% stove efficiency based on data received by Efficiency Vermont on 08/21/2017 from the upcoming NMR Vermont Residential Market Assessment; and 22.0 MMBtu/cord heat content from the November 2016 VT Fuel Price Report. %stove is calculated as ((53% (4.8 cords/yr \* 22.0 MMBtu/cord \* 68% / 80.832)) + (47% (2.1 cords/yr \* 22.0 MMBtu/cord \* 68% / 80.832)). See %stove tab in file EVT\_Pellet Wood Stove\_Analysis\_Aug 2018\_v2.xlsx for calculation. “ [↑](#footnote-ref-145)
146. 2023 Vermont Tier III TRM. “FLH for stoves estimated by the Biomass Energy Resource Center” [↑](#footnote-ref-146)
147. 2023 Vermont Tier III TRM. “Efficiency of existing wood stove being replaced is an estimate provided by the Biomass Energy Resource Center based on review of information provided by the Alliance for Green Heat.” [↑](#footnote-ref-147)
148. 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. [↑](#footnote-ref-148)
149. 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. [↑](#footnote-ref-149)
150. 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. [↑](#footnote-ref-150)
151. <https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.about> [↑](#footnote-ref-151)
152. 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. [↑](#footnote-ref-152)
153. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-153)
154. 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). [↑](#footnote-ref-154)
155. 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. [↑](#footnote-ref-155)
156. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England [↑](#footnote-ref-156)
157. 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.” [↑](#footnote-ref-157)
158. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-158)
159. 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.” [↑](#footnote-ref-159)
160. 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.“ [↑](#footnote-ref-160)
161. Ibid. [↑](#footnote-ref-161)
162. 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. [↑](#footnote-ref-162)
163. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-163)
164. 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). [↑](#footnote-ref-164)
165. 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. [↑](#footnote-ref-165)
166. 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. [↑](#footnote-ref-166)
167. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England [↑](#footnote-ref-167)
168. 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.” [↑](#footnote-ref-168)
169. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-169)
170. 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.” [↑](#footnote-ref-170)
171. 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.“ [↑](#footnote-ref-171)
172. Ibid. [↑](#footnote-ref-172)
173. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-173)
174. 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). [↑](#footnote-ref-174)
175. 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. [↑](#footnote-ref-175)
176. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England. [↑](#footnote-ref-176)
177. 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.” [↑](#footnote-ref-177)
178. 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.” [↑](#footnote-ref-178)
179. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-179)
180. 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.” [↑](#footnote-ref-180)
181. [↑](#footnote-ref-181)
182. 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.” [↑](#footnote-ref-182)
183. 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. [↑](#footnote-ref-183)
184. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-184)
185. 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). [↑](#footnote-ref-185)
186. 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. [↑](#footnote-ref-186)
187. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England. [↑](#footnote-ref-187)
188. 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.” [↑](#footnote-ref-188)
189. Consistent with New York TRM v11 and Illinois TRM v12.0 measure life assumptions. [↑](#footnote-ref-189)
190. 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’.” [↑](#footnote-ref-190)
191. Slipstream, “MN Department of Commerce TRMAC: Cold Climate VRF – Does It Work in Minnesota?” November 29, 2023. [↑](#footnote-ref-191)
192. 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. [↑](#footnote-ref-192)
193. Derived from Cadmus, 2021 Vermont Business Sector Market Characterization and Assessment Study, Final Report, Figure 49. “Other” fuel category removed. [↑](#footnote-ref-193)
194. 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). [↑](#footnote-ref-194)
195. 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. [↑](#footnote-ref-195)
196. Derived from US Energy Information Commercial Building Energy Consumption Survey (CBECS) 2018 data. Table B21, New England [↑](#footnote-ref-196)
197. 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.” [↑](#footnote-ref-197)
198. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-198)
199. 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%. [↑](#footnote-ref-199)
200. 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.“ [↑](#footnote-ref-200)
201. A simple average is assumed in the absence of data on prevalence of pool cover use. [↑](#footnote-ref-201)
202. Average ground water temperature for Burlington, Montpelier, Rutland, and Springfield, VT from U.S. DOE Standard Building America DHW Schedules, May 2014 [↑](#footnote-ref-202)
203. Buscemi, A. et al. *A Novel Model to Assess the Energy Demand of Outdoor Swimming Pools.* Energy Conversion and Management, 2024. [↑](#footnote-ref-203)
204. 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.“ [↑](#footnote-ref-204)
205. Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. “5 years is based on the parts warranty on heat pump pool water heaters.” [↑](#footnote-ref-205)
206. 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” [↑](#footnote-ref-206)
207. 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. [↑](#footnote-ref-207)
208. 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. [↑](#footnote-ref-208)
209. 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. [↑](#footnote-ref-209)
210. 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”. [↑](#footnote-ref-210)
211. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer , page 178, footnote 12 [↑](#footnote-ref-211)
212. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer , page 178, footnote 11 [↑](#footnote-ref-212)
213. 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. [↑](#footnote-ref-213)
214. 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. [↑](#footnote-ref-214)
215. 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"” [↑](#footnote-ref-215)
216. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer, page 176, footnote 2 [↑](#footnote-ref-216)
217. 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. [↑](#footnote-ref-217)
218. 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"” [↑](#footnote-ref-218)
219. 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. [↑](#footnote-ref-219)
220. Efficiency Vermont TRM Program Year 2023, ENERGY STAR Clothes Dryer. Source reference not provided. [↑](#footnote-ref-220)
221. 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>“ [↑](#footnote-ref-221)
222. 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>“ [↑](#footnote-ref-222)
223. 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. [↑](#footnote-ref-223)
224. Energy+Environmental Economics. *Residential Building Electrification in California: Consumer economics, greenhouse gases and grid impacts*. April 2019. Figure 2-8, p. 34. [↑](#footnote-ref-224)
225. 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.“ [↑](#footnote-ref-225)
226. 2023 Vermont Tier III TRM, Residential Induction Stovetop. “Table 6: Energy Model Assumptions, Residential Cooktop Performance Energy Comparison, Frontier Energy, July 2019.” [↑](#footnote-ref-226)
227. 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.” [↑](#footnote-ref-227)
228. 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. [↑](#footnote-ref-228)
229. Ibid. [↑](#footnote-ref-229)
230. Weighted-average of electric, natural gas, and propane incremental costs using unknown building type mix in Table 2. [↑](#footnote-ref-230)
231. 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. [↑](#footnote-ref-231)
232. 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. [↑](#footnote-ref-232)
233. 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. [↑](#footnote-ref-233)
234. 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.” [↑](#footnote-ref-234)
235. 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 Internation 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.” [↑](#footnote-ref-235)
236. 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. [↑](#footnote-ref-236)
237. Energy Center of Wisconsin, *Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research,* 2008, page 31. [↑](#footnote-ref-237)
238. *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.” [↑](#footnote-ref-238)
239. 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. [↑](#footnote-ref-239)
240. Illinois TRM v12.0. “Fe 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 (Ef in MMBTU/yr) and Eae (kWh/yr). An average of a 300 record sample (non-random) out of 1495 was 3.14%.” [↑](#footnote-ref-240)
241. 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. [↑](#footnote-ref-241)
242. Illinois TRM v12.0. As recommended in Navigant ‘ComEd Effective Useful Life Research Report’, May 2018. [↑](#footnote-ref-242)
243. Efficiency Vermont TRM Program Year 2023, HPwES 2.0 Airsealing. No reference given. [↑](#footnote-ref-243)
244. 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. [↑](#footnote-ref-244)
245. 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. [↑](#footnote-ref-245)
246. 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. [↑](#footnote-ref-246)
247. 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. [↑](#footnote-ref-247)
248. *Efficiency Vermont TRM Program Year 2023,* HPwES 2.0 Insulation: Attic and/or Basement, page 302, footnote 5*.*  [↑](#footnote-ref-248)
249. 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. [↑](#footnote-ref-249)
250. Energy Center of Wisconsin, *Central Air Conditioning in Wisconsin: A Compilation of Recent Field Research,* 2008, page 31. [↑](#footnote-ref-250)
251. *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.” [↑](#footnote-ref-251)
252. 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. [↑](#footnote-ref-252)
253. Illinois TRM v12.0. “Fe 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 (Ef in MMBTU/yr) and Eae (kWh/yr). An average of a 300 record sample (non-random) out of 1495 was 3.14%.” [↑](#footnote-ref-253)
254. Insulation tables are derived from ASHRAE 90.1-2016 Normative Appendix A. [↑](#footnote-ref-254)
255. *Efficiency Vermont TRM Program Year 2023,* HPwES 2.0 Insulation: Attic and/or Basement, HPwES 2.0 Insulation: Exterior Walls. [↑](#footnote-ref-255)
256. Ibid. [↑](#footnote-ref-256)
257. NEEA Advanced Water Heating Specification Version 8.1. July 15, 2024. <https://neea.org/img/documents/Advanced-Water-Heating-Specification.pdf> [↑](#footnote-ref-257)
258. Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. [↑](#footnote-ref-258)
259. 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. [↑](#footnote-ref-259)
260. 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. [↑](#footnote-ref-260)
261. 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. [↑](#footnote-ref-261)
262. 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-neea-spec-2021.xlsx.” [↑](#footnote-ref-262)
263. 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-neea-spec-2021.xlsx.” [↑](#footnote-ref-263)
264. 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?gId=6&ctId=270>“ [↑](#footnote-ref-264)
265. 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).” [↑](#footnote-ref-265)
266. Efficiency Vermont TRM 2023, HPWH. “Average Full Cost Heat Pump Water Heater for 60, 66 & 80 gallon capacity categories (NEEP 2016).” [↑](#footnote-ref-266)
267. Existing faucets are assumed to comply with the federal standard which is 2.2 GPM at 60 psi. 10 CFR § 430.32. [↑](#footnote-ref-267)
268. 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. [↑](#footnote-ref-268)
269. Efficiency Vermont Technical Reference Manual. 2023. Average flow rate of products on the WaterSense Labeled Products list as of October 18, 2022. [↑](#footnote-ref-269)
270. Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. [↑](#footnote-ref-270)
271. Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 5, 6, 18, and 19. [↑](#footnote-ref-271)
272. 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. [↑](#footnote-ref-272)
273. Ibid. [↑](#footnote-ref-273)
274. 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. [↑](#footnote-ref-274)
275. 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. [↑](#footnote-ref-275)
276. 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.

     Additonal 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. [↑](#footnote-ref-276)
277. Illinois Technical Reference Manual. V12.0. September 2023. Effective January 2024. [↑](#footnote-ref-277)
278. Ibid. [↑](#footnote-ref-278)
279. 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 [↑](#footnote-ref-279)
280. Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 12, 13. [↑](#footnote-ref-280)
281. Efficiency Vermont Technical Reference Manual. 2023. Measure lifetime from California DEER. See file DEER2014-EUL-table-update\_2014-02-05.xlsx. [↑](#footnote-ref-281)
282. Efficiency Vermont Technical Reference Manual. 2023. See footnotes 21-23. [↑](#footnote-ref-282)
283. “Vermont 2018”. Appliance Standards Awareness Project, https://appliance-standards.org/state-legislation/vermont-2018. [↑](#footnote-ref-283)
284. Existing showerheads are assumed to comply with the federal standard which is 2.5 GPM at 80 psi. 10 CFR § 430.32 [↑](#footnote-ref-284)
285. 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 [↑](#footnote-ref-285)
286. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnote 10 [↑](#footnote-ref-286)
287. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnote 11 [↑](#footnote-ref-287)
288. Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. [↑](#footnote-ref-288)
289. Efficiency Vermont Technical Reference Manual. 2023. Faucet Aerator. See footnotes 5, 6, 18, and 19. [↑](#footnote-ref-289)
290. Cadmus and Opinion Dynamics, for the Michigan Evaluation Working Group, "Showerhead and Faucet Aerator Meter Study Memorandum," June 2013, page 11, Table 7. [↑](#footnote-ref-290)
291. 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. [↑](#footnote-ref-291)
292. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197 [↑](#footnote-ref-292)
293. Cadmus and Opinion Dynamics Showerhead and Faucet Aerator Meter Study Memorandum dated June 2013, directed to Michigan Evaluation Working Group. [↑](#footnote-ref-293)
294. Ibid. [↑](#footnote-ref-294)
295. 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. [↑](#footnote-ref-295)
296. 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 (EPAct). 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” [↑](#footnote-ref-296)
297. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 16 [↑](#footnote-ref-297)
298. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 17 [↑](#footnote-ref-298)
299. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 196. See footnotes 12, 13. [↑](#footnote-ref-299)
300. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 197. See footnote 21 [↑](#footnote-ref-300)
301. Efficiency Vermont Technical Reference Manual. 2023. Low Flow Showerhead. Page 198. See footnotes 22 – 25. [↑](#footnote-ref-301)
302. “Vermont 2018”. Appliance Standards Awareness Project, https://appliance-standards.org/state-legislation/vermont-2018. [↑](#footnote-ref-302)
303. See <https://solar-rating.org> for certified product list. [↑](#footnote-ref-303)
304. Derived from NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study. [↑](#footnote-ref-304)
305. 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. [↑](#footnote-ref-305)
306. 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-neea-spec-2021.xlsx.” [↑](#footnote-ref-306)
307. Act 56 Tier III Planning Tool PY2024\_2\_13\_2024.xlsx. [↑](#footnote-ref-307)
308. 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. [↑](#footnote-ref-308)
309. 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. [↑](#footnote-ref-309)
310. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 204 [↑](#footnote-ref-310)
311. Ibid. [↑](#footnote-ref-311)
312. 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. [↑](#footnote-ref-312)
313. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats. [↑](#footnote-ref-313)
314. Derived from NMR Group, *2020 Vermont Single Family Existing Homes Baseline Study*. The mean HSPF of Heat Pump Systems is 11.2. [↑](#footnote-ref-314)
315. Efficiency Vermont TRM Program Year 2023, Central Wood Pellet Boilers and Furnaces. “Efficiency of existing wood heating systems based on professional judgment.” [↑](#footnote-ref-315)
316. Calculated using assumptions from Efficiency Vermont TRM Program Year 2023, Advanced Thermostats (Capacity = Gas Heating Consumption × 1,000,000/EFLHheat × %Controlled [↑](#footnote-ref-316)
317. Calculated using assumptions from Efficiency Vermont TRM Program Year 2023, Advanced Thermostats (Capacity = Elec Heating Consumption × 3412/EFLHheat × %Controlled × COPheat) where COPheat = 3.72. [↑](#footnote-ref-317)
318. 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. [↑](#footnote-ref-318)
319. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 206, footnote 14,15 [↑](#footnote-ref-319)
320. 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. [↑](#footnote-ref-320)
321. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 206, footnote 3 [↑](#footnote-ref-321)
322. 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. [↑](#footnote-ref-322)
323. 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. [↑](#footnote-ref-323)
324. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats. [↑](#footnote-ref-324)
325. Ibid. [↑](#footnote-ref-325)
326. Efficiency Vermont TRM Program Year 2023, Advanced Thermostats, page 207 [↑](#footnote-ref-326)
327. Ibid. [↑](#footnote-ref-327)
328. 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.” [↑](#footnote-ref-328)
329. Efficiency Vermont 2023 TRM. “Residential FLH for new construction is a weighted average of FLH for boilers and furnances in new homes. Boiler and furnace weightings from page 47, Table 47, NMR Group, "Vermont Residential New Construction Baseline Study Analysis of On-Site Audits (Draft Report)," Prepared by NMR Group for Vermont DPS, May 12, 2017. Combined appliances, wood stoves and furnaces, pellet stoves, natural gas units, and heat pumps removed. Values for Efficiency Vermont used. 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. See ‘VGS Usage Regression Work\_04182017.xls’ for analysis. 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. See ‘VGS Usage Regression Work\_04182017.xls’ for analysis.” [↑](#footnote-ref-329)
330. 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.” [↑](#footnote-ref-330)
331. Efficiency Vermont 2023 TRM. “Efficiency of new wood heating systems based on professional judgment.” [↑](#footnote-ref-331)
332. Efficiency Vermont 2023 TRM. “Efficiency of existing wood heating systems based on professional judgment.” [↑](#footnote-ref-332)
333. 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.” [↑](#footnote-ref-333)
334. 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. [↑](#footnote-ref-334)
335. Efficiency Vermont 2023 TRM, Central Wood Pellet Boilers and Furnaces. “The baseline full installation cost for residential NC is based on the percentage of each heating system in new Vermont homes from NMR Group, "Vermont Residential New Construction Baseline Study Analysis of On-Site Audits (Draft Report)," Prepared by NMR Group for Vermont DPS, May 12, 2017: page 47, Table 47 (Efficiency Vermont data). Combined appliances and natural gas and pellet systems excluded. Full installation costs for baseline heating systems, except for cordwood furnaces, are the average of typical residential costs for years 2013 and 2020 from U.S. EIA, "Updated Buildings Sector Appliance and Equipment Costs and Efficiencies," November 2016. Cordwood furnaces are assumed to cost the same as pellet furnaces ($20,000). See EVT\_Central Wood Pellet Boilers and Furnaces\_Analysis\_Jan 2018.xlsx for measure cost calculations.” [↑](#footnote-ref-335)
336. 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.” [↑](#footnote-ref-336)
337. 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. [↑](#footnote-ref-337)
338. 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 pelelts 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.” [↑](#footnote-ref-338)
339. 2023 Vermont Tier III TRM. “%stove for wood stoves is calculating using: the percentage of primary (53%) versus supplemental (47%) cordwood users in Vermont and the annual number of cords burned by primary (4.8) versus supplemental (2.1) cordwood users from Vermont Department of Forests, Parks, and Recreation, "Vermont Residential Fuel Assessment for the 2014-2015 Heating Season," March 2016, page 6; 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); 68% stove efficiency based on data received by Efficiency Vermont on 08/21/2017 from the upcoming NMR Vermont Residential Market Assessment; and 22.0 MMBtu/cord heat content from the November 2016 VT Fuel Price Report. %stove is calculated as ((53% (4.8 cords/yr \* 22.0 MMBtu/cord \* 68% / 80.832)) + (47% (2.1 cords/yr \* 22.0 MMBtu/cord \* 68% / 80.832)). See %stove tab in file EVT\_Pellet Wood Stove\_Analysis\_Aug 2018\_v2.xlsx for calculation. “ [↑](#footnote-ref-339)
340. 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.” [↑](#footnote-ref-340)
341. 2023 Vermont Tier III TRM. “FLH for stoves estimated by the Biomass Energy Resource Center” [↑](#footnote-ref-341)
342. 2023 Vermont Tier III TRM. “Efficiency of existing wood stove being replaced is an estimate provided by the Biomass Energy Resource Center based on review of information provided by the Alliance for Green Heat.” [↑](#footnote-ref-342)
343. 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. [↑](#footnote-ref-343)
344. 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. [↑](#footnote-ref-344)
345. 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. [↑](#footnote-ref-345)
346. 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. [↑](#footnote-ref-346)
347. 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. [↑](#footnote-ref-347)
348. 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. [↑](#footnote-ref-348)
349. 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. [↑](#footnote-ref-349)
350. 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. [↑](#footnote-ref-350)
351. 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.” [↑](#footnote-ref-351)
352. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-352)
353. 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.” [↑](#footnote-ref-353)
354. 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%20%202022.pdf>, accessed August 15, 2024. [↑](#footnote-ref-354)
355. 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. [↑](#footnote-ref-355)
356. 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. [↑](#footnote-ref-356)
357. 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. [↑](#footnote-ref-357)
358. 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. [↑](#footnote-ref-358)
359. 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. [↑](#footnote-ref-359)
360. 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.” [↑](#footnote-ref-360)
361. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-361)
362. 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.” [↑](#footnote-ref-362)
363. 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. [↑](#footnote-ref-363)
364. 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. [↑](#footnote-ref-364)
365. 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. [↑](#footnote-ref-365)
366. 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. [↑](#footnote-ref-366)
367. 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. [↑](#footnote-ref-367)
368. 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.” [↑](#footnote-ref-368)
369. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-369)
370. 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..” [↑](#footnote-ref-370)
371. 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%20%202022.pdf>, accessed August 15, 2024. [↑](#footnote-ref-371)
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. [↑](#footnote-ref-372)
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. [↑](#footnote-ref-373)
374. 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. [↑](#footnote-ref-374)
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. [↑](#footnote-ref-375)
376. 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. [↑](#footnote-ref-376)
377. 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.” [↑](#footnote-ref-377)
378. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-378)
379. 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..” [↑](#footnote-ref-379)
380. 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. [↑](#footnote-ref-380)
381. 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. [↑](#footnote-ref-381)
382. 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.” [↑](#footnote-ref-382)
383. 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. [↑](#footnote-ref-383)
384. Illinois TRM v12.0. “Based on DOE Rulemaking Technical Support document, as recommended in Guidehouse ‘ComEd Effective Useful Life Research Report’, May 2018.” [↑](#footnote-ref-384)
385. 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.” [↑](#footnote-ref-385)
386. 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.” [↑](#footnote-ref-386)
387. Baseline and proposed conditions align with the *2023 Efficiency Vermont TRM* definitions for ERV/HRV. [↑](#footnote-ref-387)
388. “New Metric Available for HRV and ERV Performance”. Home Ventilating Institute, <https://www.hvi.org/resources/publications/builder-guide>. [↑](#footnote-ref-388)
389. 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. [↑](#footnote-ref-389)
390. 2023 Efficiency Vermont TRM,ERV/HRV. Assumes 58°F base temperature. [↑](#footnote-ref-390)
391. *Ibid*. [↑](#footnote-ref-391)
392. 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. [↑](#footnote-ref-392)
393. Calculated with TMY3 data for Burlington, VT. Assumes return air enthalpy of 25.3 Btu/lb based on 70°F at 50% relative humidity. [↑](#footnote-ref-393)
394. NMR Group, *2020 Vermont Single Family Existing Homes Baseline Study*, statewide mean value, Table 83. [↑](#footnote-ref-394)
395. 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.” [↑](#footnote-ref-395)
396. *2023 Efficiency Vermont TRM,* ERV/HRV*.* “Consistent with Tracker default assumptions.” [↑](#footnote-ref-396)
397. *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.” [↑](#footnote-ref-397)
398. 2020 Vermont Residential Building Energy Standards, R403.6. [↑](#footnote-ref-398)
399. 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. [↑](#footnote-ref-399)
400. 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. [↑](#footnote-ref-400)
401. 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. [↑](#footnote-ref-401)
402. 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. [↑](#footnote-ref-402)
403. 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. [↑](#footnote-ref-403)
404. 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.” [↑](#footnote-ref-404)
405. Consistent with New York TRM v11 and Illinois TRM v12.0 measure life assumptions. [↑](#footnote-ref-405)
406. 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’.” [↑](#footnote-ref-406)
407. 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. [↑](#footnote-ref-407)
408. Efficiency Vermont 2023 TRM, workbook “AMH2023-Modelling\_082823”. [↑](#footnote-ref-408)
409. <https://www.ecfr.gov/current/title-24/subtitle-B/chapter-XX/part-3280>, accessed August 22, 2024. [↑](#footnote-ref-409)
410. <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. [↑](#footnote-ref-410)
411. <https://www.energy.gov/sites/default/files/2022-12/DOE%20ZERH%20MH%20V1%20National%20Program%20Requirements.pdf>, accessed August 22, 2024. [↑](#footnote-ref-411)
412. NMR Group, 2020 Vermont Single Family Existing Homes Baseline Study, Table 104. [↑](#footnote-ref-412)
413. 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%. [↑](#footnote-ref-413)
414. 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.“ [↑](#footnote-ref-414)
415. A simple average is assumed in the absence of data on prevalence of pool cover use. [↑](#footnote-ref-415)
416. Average ground water temperature for Burlington, Montpelier, Rutland, and Springfield, VT from U.S. DOE Standard Building America DHW Schedules, May 2014 [↑](#footnote-ref-416)
417. Buscemi, A. et al. *A Novel Model to Assess the Energy Demand of Outdoor Swimming Pools.* Energy Conversion and Management, 2024. [↑](#footnote-ref-417)
418. Vermont 2023 Tier III TRM, Heat Pump Pool Water Heater. “5 years is based on the parts warranty on heat pump pool water heaters.” [↑](#footnote-ref-418)
419. 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” [↑](#footnote-ref-419)