

# ResStock 2024.2 Release: Technical Documentation

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# 1. ResStock and Its Updates Since the 2022.1 Release

## 1.1. ResStock Tool Description

ResStock™ is a tool that models the energy consumption of the U.S. housing stock. It is developed and maintained by the National Renewable Energy Laboratory (NREL). Its two main functions are (1) the creation of statistically representative building models that are informed by available data and (2) the physics-based simulation of these models using EnergyPlus™ and OpenStudio™. The resulting ResStock dataset includes the energy consumption of each modeled dwelling unit and its respective dwelling unit characteristics (e.g., insulation levels, foundation type, wall construction) and household characteristics (e.g., setpoint properties, occupant information, household income). A dwelling unit is a single housing residence, such as one townhome, a single apartment within an apartment building, or a single-family detached home.

ResStock utilizes both actual meteorological year (AMY) historical weather files as well as typical meteorological year (TMY3) weather files when modeling building energy use. A key feature of ResStock is its ability to model the existing U.S. building stock with the addition of “what-if” scenarios including energy efficiency measures—for example, quantifying the energy savings if the entire housing stock was upgraded to R-60 attic insulation.

In the End-Use Savings Shapes (EUSS) datasets, this feature is used with various envelope, equipment, and electrification measures that are bundled together into measure packages. EUSS dataset users can obtain timeseries and annual energy use data from the existing, or “baseline”, housing stock and each measure package on the [ResStock datasets website](#). The 2022.1 dataset includes 10 measure packages across three weather years. This dataset release—2024.2—includes 16 measure packages across two weather years and incorporates the ResStock improvements described in Section 1.2. A summary of ResStock timeseries data releases can be found in

Table 1.

Table 1. Summary of ResStock Datasets, Features, and Key Outputs

ResStock Dataset Release	2021.1	2022.1	2024.2
<b>Features</b>			
Weather Year(s)	TMY3 AMY2018	TMY3 AMY2018 AMY2012	TMY3 AMY2018
Approximate Housing Stock Year Represented	2018	2018	2018
Timeseries Results	X	X	X
Annual Results	X	X	X
Number of Measure Packages	0	10	15
Number of Dwelling Models in Baseline	550,000	550,000	550,000
<b>Output Metrics<sup>1</sup></b>			
Energy	X	X	X
Carbon Emissions		X	X
Utility Bills			X
Indoor Air Temperature		X	X

<sup>1</sup> See Section 3 for more information on outputs.

Table 1 describes all ResStock timeseries datasets released as of this report. Features and key output metrics that are included in each dataset are marked with an X or the relevant value.

### ***Dwelling Unit and Household Characteristics Information***

Dwelling unit and household characteristics are determined via ResStock’s quota-based sampling of each characteristic’s respective probability distributions. These distributions are created from datasets such as the U.S. Energy Information Administration’s (EIA) Residential Energy Consumption Survey (RECS) and U.S. census data. In most recent datasets, the household characteristics include metrics useful for equity-centered analysis—income, area median income, federal poverty level, and tenure (renter/owner) status. Specific source information is contained in the [housing characteristic files](#) on this dataset’s ResStock GitHub repository.

Calibration and validation of ResStock was completed in 2021 through the End-Use Load Profiles (EULP) project using EIA Form 861 monthly energy reporting and load research data as well as smart meter data from a handful of utilities across the United States.<sup>2</sup> Still, discrepancies are possible between ResStock data and place-based housing stock knowledge or databases (such as tax assessors), particularly at smaller geographies, such as census tract and census block.

### ***Sample Size Constraints***

The smallest geography available in ResStock is the intersection of county and [Public Use Microdata Area](#).<sup>3</sup> ResStock captures what the existing U.S. housing stock looks like both in diversity and geospatial distribution, but the individual building samples do not correspond to any buildings that can be found on maps; they are only a statistical representation. However, it can be valuable to use ResStock data to estimate energy impacts of real buildings based on similar dwelling unit characteristics. Analyses using this dataset should estimate standard error for metrics of interest using the standard deviation divided by the square root of the number of samples (i.e., profiles or models). As discussed in Section 5.1.3 of Wilson et al.,<sup>4</sup> for residential units, a good rule of thumb is to use at least 1000 samples to maintain 15% or less sampling discrepancy for common quantities of interest.

### ***Representative Number of Dwellings for Each Modeled Dwelling Unit***

Each modeled dwelling unit in this dataset is representative of a specific number of real-world dwellings. The specific number for this dataset is 252.3 dwellings. When using data from individual buildings, this number can be used to scale up a model’s timeseries or annual outputs to what a representative total would be. This scaling is not necessary if viewing data in the data viewer or if using pre-aggregated timeseries data files from the OEDI data repository.

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<sup>2</sup> Wilson, Eric J.H., Andrew Parker, Anthony Fontanini, Elaina Present, Janet L. Reyna, Rajendra Adhikari, Carlo Bianchi, et al. 2022. *End-Use Load Profiles for the U.S. Building Stock*. Washington, DC: U.S. Department of Energy. <https://www.nrel.gov/docs/fy22osti/80889.pdf>

<sup>3</sup> Public Use Microdata Areas are defined by the U.S. census to contain at least 100,000 people.

<sup>4</sup> Wilson, Eric J.H., Andrew Parker, Anthony Fontanini, Elaina Present, Janet L. Reyna, Rajendra Adhikari, Carlo Bianchi, et al. 2022. *End-Use Load Profiles for the U.S. Building Stock*. Washington, DC: U.S. Department of Energy. <https://www.nrel.gov/docs/fy22osti/80889.pdf>

## 1.2. Model Updates Since the 2022.1 Dataset Release

### **RECS 2020 Update**

This 2024.2 dataset includes updated information from the recently released [RECS 2020](#). Information included in RECS includes energy use patterns, housing unit characteristics, and household demographics. Household and dwelling characteristics in ResStock that were updated to include information from RECS 2020 include the following parameters:

- Geometry
  - Geometry Floor Area Bin; Geometry Attic Type; Geometry Garage; Geometry Space Combination
- Appliances
  - Refrigerator; Misc Extra Refrigerator; Clothes Dryer; Clothes Washer; Clothes Washer Presence; Cooking Range; Dishwasher; Misc Freezer; Misc Hot Tub Spa; Misc Pool; Misc Pool Heater
- HVAC and Water Heating
  - Water Heater Efficiency; Water Heater Fuel; Water Heater In Unit; Water Heater Location; HVAC Cooling Type; HVAC Heating Type; HVAC Heating Efficiency; HVAC Cooling Efficiency; HVAC Has Ducts; HVAC Has Shared System; HVAC Shared Efficiencies
- Envelope
  - Windows; Roof Material
- Household Characteristics
  - Cooling Setpoint; Cooling Setpoint Has Offset; Cooling Setpoint Offset Magnitude; Cooling Setpoint Offset Period; Heating Setpoint; Heating Setpoint Has Offset; Heating Setpoint Offset Magnitude; Heating Setpoint Offset Period.

More information can be found in the [source report](#) of this dataset's ResStock GitHub repository.

### **Geothermal Heat Pump Modeling**

Improved geothermal heat pump modeling capabilities have been added to ResStock since the 2022.1 dataset release. ResStock had the capability to model geothermal heat pumps previously, but the model methodology was outdated and lacked documentation of the methodology, data sources, and assumptions. Recent funding from the U.S. Department of Energy Geothermal Technologies Office to revive geothermal heat pump modeling in OpenStudio-HPXML allowed the ResStock team to incorporate the modeling of geothermal heat pumps. During this funded effort, many aspects of the model and the default values were changed. Some of the major improvements include:

- Expanding the HPXML input schema with industry guidance
- Alignment of fan and pump energy with [ISO 13256-1](#)
- Single-speed performance curves updated to a new product line (ClimateMaster Tranquility TS)
- Assignment of the undistributed ground temperature by interpolating from over 1,000 locations in North America

- Allowing the ground thermal conductivity to vary by climate zone
- Ground heat exchanger [g-function](#) integration with [GHEDesigner](#) (a software package to obtain g-functions of various vertical borehole/borefield configurations)
- Expanding the available ground heat exchanger configurations to include rectangle, L, lopsided U, U, C, zoned rectangle, and open rectangle options.

In this dataset’s geothermal heat pump measure packages, most geothermal heat pump properties are sized automatically (number of boreholes, borehole length, and loop flow) or have default values (grout type and conductivity, pipe properties, borehole spacing, borefield configuration, and soil diffusivity). Efficiency levels for geothermal heat pumps are tied to coefficient of performance (COP) and energy efficiency ratio (EER).

### **Variable Speed HVAC Updates**

Assumptions for variable speed air conditioners, central heat pumps, and minisplit heat pumps have been updated since the release of the 2022.1 dataset. Data from the [Northeast Energy Efficiency Partnerships \(NEEP\) Cold Climate Air Source Heat Pump List](#) were used to update conversions from SEER/HSPF efficiency values to nominal COPs. Additionally, data from NEEP were used to update the variable speed performance curves used by EnergyPlus when modeling variable speed HVAC systems for ResStock models. These updates provided detailed heating and cooling performance data as inputs for variable speed HVAC models, including capacity retention fractions at different outdoor temperatures. For example, measure package 2 and measure package 3 have capacity retentions of 90% at 5°F. These capacity retention settings paired with updated performance curves from the NEEP Cold Climate Air Source Heat Pump List allow for variable speed heat pump modeling that is more reflective of actual performance and operating conditions of cold climate heat pumps. For more information on how these changes were implemented within the OpenStudio-HPXML workflow, see the [pull request description](#) on the OpenStudio-HPXML GitHub repository.

## **2. Measure Package Composition and Logic**

### **2.1. Measure Package Selection Process**

The measure packages from this dataset were chosen based on feedback and comments from a diverse set of stakeholders and users of ResStock datasets. If there are measure packages or other technologies you would like to see in a future ResStock dataset, please e-mail our team at [ResStock@nrel.gov](mailto:ResStock@nrel.gov).

The 2024.2 dataset comprises 16 measure packages, described in Section 2.2.

### **2.2. Measure Package Descriptions**

#### ***Measure Package 1: ENERGY STAR Air-to-Air Heat Pump With Electric Backup***

##### *Summary*

- ENERGY STAR® air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts



- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit.
- Only applies to dwelling units with an existing primary heating fuel of electricity, natural gas, propane, or fuel oil. Excludes homes with other heating fuels (e.g., wood) or no heating system in the baseline.

*Technical Description*

- Centrally ducted air-source heat pump (ASHP) SEER1 16, 9.2 HSPF1<sup>5</sup>
  - Applicability
    - Dwellings with:
      - ducts
      - primary heating fuel of electricity, natural gas, propane, or fuel oil
      - no shared HVAC
  - Performance
    - Single-stage
    - Sized to ACCA Manual S/J
    - Backup heat provided by electric resistance, active when the heat pump cannot meet the load
    - Capacity retention of 50% @ 5°F
    - Partial space conditioning set to 100%
- Non-ducted minisplit heat pump (MSHP) SEER1 16, 9.2 HSPF1
  - Applicability
    - Dwellings with:
      - Primary heating fuel of electricity, natural gas, propane, or fuel oil
      - Either:
        - No ducts
        - All of the following:
          - Ducts
          - Shared HVAC
          - In a building other than a multi-family high-rise building (ie <8 stories)
  - Performance
    - Variable speed
    - Sized to max load
    - Backup heat provided by electric resistance, active when the heat pump cannot meet the load
    - Capacity retention of 50% @ 5°F
    - Remove setpoint offsets
    - Partial space conditioning set to 100%.

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<sup>5</sup> SEER2 and HSPF2 conversions are provided in Table 3.

## Measure Package 2: High Efficiency Cold-Climate Air-to-Air Heat Pump With Electric Backup

### Summary

- High efficiency cold-climate air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts
- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit.
- Only applies to dwelling units with an existing primary heating fuel of electricity, natural gas, propane, or fuel oil. Excludes homes with other heating fuels (e.g., wood) or no heating system in the baseline.
- 

### Technical Description

- Centrally ducted ASHP SEER1 20, 11 HSPF1
  - Applicability
    - Dwellings with:
      - ducts
      - primary heating fuel of electricity, natural gas, propane, or fuel oil
      - no shared HVAC
  - Performance
    - Variable speed
    - Sized to max load
    - Backup heat provided by electric resistance, active when the heat pump cannot meet the load
    - Capacity retention of 90% @ 5°F
    - Remove setpoint offsets
    - Partial space conditioning set to 100%
- Non-ducted MSHP SEER1 20, 11 HSPF1
  - Applicability
    - Dwellings with:
      - Primary heating fuel of electricity, natural gas, propane, or fuel oil
      - Either:
        - No ducts
        - All of the following:
          - Ducts
          - Shared HVAC
          - In a building other than a multi-family high-rise building (ie <8 stories)
  - Performance
    - Variable speed
    - Sized to max load

- Backup heat provided by electric resistance, active when the heat pump cannot meet the load
- Capacity retention of 90% @ 5°F
- Remove setpoint offsets
- Partial space conditioning set to 100%.

### **Measure Package 3: Ultra High Efficiency Air-to-Air Heat Pump With Electric Backup**

#### *Summary*

- Ultra high efficiency air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts
- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit.
- Only applies to dwelling units with an existing primary heating fuel of electricity, natural gas, propane, or fuel oil. Excludes homes with other heating fuels (e.g., wood) or no heating system in the baseline.
- 

#### *Technical Description*

- Centrally ducted ASHP SEER1 24, 13 HSPF1
  - Applicability
    - Dwellings with:
      - ducts
      - primary heating fuel of electricity, natural gas, propane, or fuel oil
    - no shared HVAC
  - Performance
    - Variable speed
    - Sized to max load
    - Backup heat provided by electric resistance, active when the heat pump cannot meet the load
    - Capacity retention of 90% @ 5°F
    - Remove setpoint offsets
    - Partial space conditioning set to 100%
- Non-ducted MSHP SEER1 24, 13 HSPF1
  - Applicability
    - Dwellings with:
      - Primary heating fuel of electricity, natural gas, propane, or fuel oil
      - Either:
        - No ducts
        - All of the following:
          - Ducts
          - Shared HVAC

- In a building other than a multi-family high-rise building (ie <8 stories)
  - Performance
    - Variable speed
    - Sized to max load
    - Backup heat provided by electric resistance, active when the heat pump cannot meet the load
    - Capacity retention of 90% @ 5°F
    - Remove setpoint offsets
    - Partial space conditioning set to 100%

### **Measure Package 4: ENERGY STAR Air-to-Air Heat Pump With Existing System as Backup**

#### *Summary*

- ENERGY STAR air-to-air heat pump with the existing fossil fuel system providing backup heat applied to all dwellings with and without ducts and with existing primary heating fuel of natural gas, propane, or fuel oil.
- Do not apply to units with shared HVAC.

#### *Technical Description*

- Centrally ducted ASHP SEER1 16, 9.2 HSPF1 with the existing heating system as an independent backup
  - Applicability
    - Dwellings with fossil fuel heating from natural gas, propane, or fuel oil, ducts, and non-shared HVAC
  - Performance
    - Single-stage
    - Sized to ACCA Manual S/J
    - Backup heat provided by existing heating, active when the heat pump cannot meet the load
      - Backup heat provided by furnaces incorporate the following lockout temperatures:
        - Compressor lockout temperature: 5°F
        - Backup heating lockout temperature: 40°F
      - Capacity retention of 50% @ 5°F
      - Partial space conditioning set to 100%
- Non-ducted MSHP SEER1 16, 9.2 HSPF1, with the existing heating system as an independent backup
  - Applicability
    - Dwellings with fossil fuel heating from natural gas, propane, or fuel oil, without ducts, and with non-shared HVAC
  - Performance

- Variable speed
- Sized to max load
- Existing heating retained as backup, active when the heat pump cannot meet the load
- Capacity retention of 50% @ 5°F
- Remove setpoint offsets
- Partial space conditioning set to 100%.

### **Measure Package 5: ENERGY STAR Geothermal Heat Pump**

#### *Summary*

- Geothermal heat pump applied to all dwellings with ducts
- Do not apply to units with shared HVAC.

#### *Technical Description*

- Centrally ducted geothermal heat pump EER 20.5, COP 4.0
  - Applicability
    - Dwelling with ducts and non-shared HVAC
  - Performance
    - Sized to max load
    - No backup system present
    - Partial space conditioning set to 100%
    - Borefield
      - Loop configuration: Vertical borehole
      - Borefield configuration: Rectangle
      - Loop length: Calculated during sizing according to [ACCA Manual J](#) load requirements.
      - Number of boreholes: Calculated during sizing with a range of 79 ft–500 ft deep
      - Loop flow rates: Autosized by calculating 3 times the maximum of the ground source heat pump’s heating/cooling capacity in tons, with a minimum of 3 gal/min.
      - Borehole diameter: 5 in
      - Borehole spacing: 16.4 ft
      - Grout type: Standard conductivity (0.75 Btu/hr-ft-F)
      - Pipe type: Standard conductivity (0.23 Btu/hr-ft-F)
      - Pipe loop diameter: 1.25 in.

### **Measure Package 6: ENERGY STAR Air-to-Air Heat Pump With Electric Backup + Light Touch Envelope**

#### *Summary*

- ENERGY STAR air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit. Only applies if primary heating fuel is electricity, natural gas, propane, or fuel oil.

#### *Technical Description*

- Measure Package 1
- If Measure Package 1 applies, also apply:
  - Attic floor insulation
    - Applies only to dwelling units with vented attics
    - Value: R-30
      - Applies to IECC 2004 climate zone 1A
      - Applies to dwelling units without insulation or with insulation less than R-30
    - Value: R-49
      - Applies to IECC 2004 climate zone 2A, 2B, 3A, 3B, 3C
      - Applies to dwelling units without insulation or with insulation less than R-49
    - Value: R-60
      - Applies to IECC 2004 climate zone 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A, 7B
      - Applies to dwelling units without insulation or with insulation less than R-60
  - Air leakage reduction
    - Value: 30% whole-home reduction in ACH50
      - Applies to all dwelling units with greater than 10 ACH50 infiltration.

#### ***Measure Package 7: High Efficiency Cold-Climate Air-to-Air Heat Pump With Electric Backup + Light Touch Envelope***

##### *Summary*

- High efficiency cold-climate air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50

- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit. Only applies if primary heating fuel is electricity, natural gas, propane, or fuel oil.

#### *Technical Description*

- Measure Package 2
- If Measure Package 2 applies, also apply:
  - Attic floor insulation
    - Applies only to dwelling units with vented attics
    - Value: R-30
      - Applies to IECC 2004 climate zone 1A
      - Applies to dwelling units without insulation or with insulation less than R-30
    - Value: R-49
      - Applies to IECC 2004 climate zone 2A, 2B, 3A, 3B, 3C
      - Applies to dwelling units without insulation or with insulation less than R-49
    - Value: R-60
      - Applies to IECC 2004 climate zone 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A, 7B
      - Applies to dwelling units without insulation or with insulation less than R-60
  - Air leakage reduction
    - Value: 30% whole-home reduction in ACH50
      - Applies to all dwelling units with greater than 10 ACH50 infiltration.

#### ***Measure Package 8: Ultra High Efficiency Air-to-Air Heat Pump With Electric Backup + Light Touch Envelope***

#### *Summary*

- Ultra high efficiency air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit. Only applies if primary heating fuel is electricity, natural gas, propane, or fuel oil.

#### *Technical Description*

- Measure Package 3
- If Measure Package 3 applies, also apply:
  - Attic floor insulation

- Applies only to dwelling units with vented attics
- Value: R-30
  - Applies to IECC 2004 climate zone 1A
  - Applies to dwelling units without insulation or with insulation less than R-30
- Value: R-49
  - Applies to IECC 2004 climate zone 2A, 2B, 3A, 3B, 3C
  - Applies to dwelling units without insulation or with insulation less than R-49
- Value: R-60
  - Applies to IECC 2004 climate zone 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A, 7B
  - Applies to dwelling units without insulation or with insulation less than R-60
- Air leakage reduction
  - Value: 30% whole-home reduction in ACH50
    - Applies to all dwelling units with greater than 10 ACH50 infiltration.

### ***Measure Package 9: ENERGY STAR Air-to-Air Heat Pump With Existing System as Backup + Light Touch Envelope***

#### *Summary*

- ENERGY STAR air-to-air heat pump with existing fossil fuel system as backup applied to all dwellings with and without ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- Do not apply to units with shared HVAC.
- Only applies if primary heating fuel is natural gas, propane, or fuel oil.

#### *Technical Description*

- Measure Package 4
- If Measure Package 4 applies, also apply:
  - Attic floor insulation
    - Applies only to dwelling units with vented attics
    - Value: R-30
      - Applies to IECC 2004 climate zone 1A
      - Applies to dwelling units without insulation or with insulation less than R-30
    - Value: R-49
      - Applies to IECC 2004 climate zone 2A, 2B, 3A, 3B, 3C
      - Applies to dwelling units without insulation or with insulation less than R-49



- Value: R-60
  - Applies to IECC 2004 climate zone 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A, 7B
  - Applies to dwelling units without insulation or with insulation less than R-60
- Air leakage reduction
  - Value: 30% whole-home reduction in ACH50
    - Applies to all dwelling units with greater than 10 ACH50 infiltration

### **Measure Package 10: ENERGY STAR Geothermal Heat Pump + Light Touch Envelope**

#### *Summary*

- Geothermal heat pump applied to all dwellings with ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- Do not apply to units with shared HVAC.
- Only applies if primary heating fuel is electricity, natural gas, propane, or fuel oil.

#### *Technical Description*

- Measure Package 5
- If Measure Package 5 applies, also apply:
  - Attic floor insulation
    - Applies only to dwelling units with vented attics
    - Value: R-30
      - Applies to IECC 2004 climate zone 1A
      - Applies to dwelling units without insulation or with insulation less than R-30
    - Value: R-49
      - Applies to IECC 2004 climate zone 2A, 2B, 3A, 3B, 3C
      - Applies to dwelling units without insulation or with insulation less than R-49
    - Value: R-60
      - Applies to IECC 2004 climate zone 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A, 7B
      - Applies to dwelling units without insulation or with insulation less than R-60
  - Air leakage reduction
    - Value: 30% whole-home reduction in ACH50
      - Applies to all dwelling units with greater than 10 ACH50 infiltration.

## **Measure Package 11: ENERGY STAR Air-to-Air Heat Pump With Electric Backup + Light Touch Envelope + Full Appliance Electrification with Efficiency**

### *Summary*

- ENERGY STAR air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- Heat pump water heaters (HPWHs) for dwellings with less efficient electric water heaters and all dwellings with gas, propane, or fuel oil water heaters
- Electric ENERGY STAR dryer for dwellings with gas or propane dryers
- Electric induction cooktop and electric oven for dwellings with gas or propane ranges
- Electric pool heater for dwellings with natural gas pool heaters
- Electric spa heater for dwellings with natural gas spa heaters
- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit.
- Only applies if primary heating fuel is electricity, natural gas, propane, or fuel oil.

### *Technical Description*

- Measure Package 6
- If heat pump from Measure Package 6 applies, also apply:
  - HPWH, 50 gal, 3.45 Uniform Energy Factor (UEF)
    - Applies to dwellings that have 3 or less bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - HPWH, 66 gal, 3.35 UEF
    - Applies to dwellings that have 4 bedrooms and an electric water heater with UEF < 3.35 or a natural gas, propane, or fuel oil water heater
  - HPWH, 80 gal, 3.45 UEF
    - Applies to dwellings that have 5 bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - ENERGY STAR electric dryer, Combined Energy Factor (CEF) 3.93
    - Applies if existing dryer uses natural gas or propane
  - Electric induction cooktop and electric oven
    - Applies if existing range uses natural gas or propane
  - Electric pool heater
    - Applies if existing pool heater uses natural gas
  - Electric spa heater
    - Applies if existing spa heater uses natural gas.

## **Measure Package 12: High Efficiency Cold-Climate Air-to-Air Heat Pump With Electric Backup + Light Touch Envelope + Full Appliance Electrification with Efficiency**

### *Summary*

- High efficiency cold-climate air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- HPWHs for dwellings with less efficient electric water heaters and all dwellings with gas, propane, or fuel oil water heaters
- Electric ENERGY STAR dryer for dwellings with gas or propane dryers
- Electric induction cooktop and electric oven for dwellings with gas or propane ranges
- Electric pool heater for dwellings with natural gas pool heaters
- Electric spa heater for dwellings with natural gas spa heaters
- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit.
- Only applies if primary heating fuel is electricity, natural gas, propane, or fuel oil.

### *Technical Description*

- Measure Package 7
- If heat pump from Measure Package 7 applies, also apply:
  - HPWH, 50 gal, 3.45 Uniform Energy Factor (UEF)
    - Applies to dwellings that have 3 or less bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - HPWH, 66 gal, 3.35 UEF
    - Applies to dwellings that have 4 bedrooms and an electric water heater with UEF < 3.35 or a natural gas, propane, or fuel oil water heater
  - HPWH, 80 gal, 3.45 UEF
    - Applies to dwellings that have 5 bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - ENERGY STAR electric dryer, CEF 3.93
    - Applies if existing dryer uses natural gas or propane
  - Electric induction cooktop and electric oven
    - Applies if existing range uses natural gas or propane
  - Electric pool heater
    - Applies if existing pool heater uses natural gas
  - Electric spa heater
    - Applies if existing spa heater uses natural gas.

## **Measure Package 13: Ultra High Efficiency Air-to-Air Heat Pump With Electric Backup + Light Touch Envelope + Full Appliance Electrification with Efficiency**

### *Summary*

- Ultra high efficiency air-to-air heat pump with electric resistance backup applied to all dwellings with and without ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- HPWHs for dwellings with less efficient electric water heaters and all dwellings with gas, propane, or fuel oil water heaters
- Electric ENERGY STAR dryer for dwellings with gas or propane dryers
- Electric induction cooktop and electric oven for dwellings with gas or propane ranges
- Electric pool heater for dwellings with natural gas pool heaters
- Electric spa heater for dwellings with natural gas spa heaters
- Do not apply to high-rise dwelling units with shared HVAC. Additionally, ducted heat pump portions of measure package will not apply to any shared HVAC dwelling unit
- Only applies if primary heating fuel is electricity, natural gas, propane, or fuel oil.

### *Technical Description*

- Measure Package 8
- If heat pump from Measure Package 8 applies, also apply:
  - HPWH, 50 gal, 3.45 Uniform Energy Factor (UEF)
    - Applies to dwellings that have 3 or less bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - HPWH, 66 gal, 3.35 UEF
    - Applies to dwellings that have 4 bedrooms and an electric water heater with UEF < 3.35 or a natural gas, propane, or fuel oil water heater
  - HPWH, 80 gal, 3.45 UEF
    - Applies to dwellings that have 5 bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - ENERGY STAR electric dryer, CEF 3.93
    - Applies if existing dryer uses natural gas or propane
  - Electric induction cooktop and electric oven
    - Applies if existing range uses natural gas or propane
  - Electric pool heater
    - Applies if existing pool heater uses natural gas
  - Electric spa heater
    - Applies if existing spa heater uses natural gas

## ***Measure Package 14: ENERGY STAR Air-to-Air Heat Pump With Existing System as Backup + Light Touch Envelope + Full Appliance Electrification with Efficiency***

### *Summary*

- ENERGY STAR air-to-air heat pump with existing fossil fuel system as backup applied to all dwellings with and without ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- HPWHs for dwellings with less efficient electric water heaters and all dwellings with gas, propane, or fuel oil water heaters
- Electric ENERGY STAR dryer for dwellings with gas or propane dryers
- Electric induction cooktop and electric oven for dwellings with gas or propane ranges
- Electric pool heater for dwellings with natural gas pool heaters
- Electric spa heater for dwellings with natural gas spa heaters
- Do not apply to units with shared HVAC.
- Only applies if primary heating fuel is natural gas, propane, or fuel oil.

### *Technical Description*

- Measure Package 9
- If heat pump from Measure Package 9 applies, also apply:
  - HPWH, 50 gal, 3.45 Uniform Energy Factor (UEF)
    - Applies to dwellings that have 3 or less bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - HPWH, 66 gal, 3.35 UEF
    - Applies to dwellings that have 4 bedrooms and an electric water heater with UEF < 3.35 or a natural gas, propane, or fuel oil water heater
  - HPWH, 80 gal, 3.45 UEF
    - Applies to dwellings that have 5 bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - ENERGY STAR electric dryer, CEF 3.93
    - Applies if existing dryer uses natural gas or propane
  - Electric induction cooktop and electric oven
    - Applies if existing range uses natural gas or propane
  - Electric pool heater
    - Applies if existing pool heater uses natural gas
  - Electric spa heater
    - Applies if existing spa heater uses natural gas.

## **Measure Package 15: ENERGY STAR Geothermal Heat Pump + Light Touch Envelope + Full Appliance Electrification with Efficiency**

### *Summary*

- Geothermal heat pump applied to all dwellings with ducts
- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50
- HPWHs for dwellings with less efficient electric water heaters and all dwellings with gas, propane, or fuel oil water heaters
- Electric ENERGY STAR dryer for dwellings with gas or propane dryers
- Electric induction cooktop and electric oven for dwellings with gas or propane ranges
- Electric pool heater for dwellings with natural gas pool heaters
- Electric spa heater for dwellings with natural gas spa heaters
- Do not apply to units with shared HVAC.
- Only applies if primary heating fuel is electricity, natural gas, propane, or fuel oil.

### *Technical Description*

- Measure Package 10
- If heat pump from Measure Package 10 applies, also apply:
  - HPWH, 50 gal, 3.45 Uniform Energy Factor (UEF)
    - Applies to dwellings that have 3 or less bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - HPWH, 66 gal, 3.35 UEF
    - Applies to dwellings that have 4 bedrooms and an electric water heater with UEF < 3.35 or a natural gas, propane, or fuel oil water heater
  - HPWH, 80 gal, 3.45 UEF
    - Applies to dwellings that have 5 bedrooms and an electric water heater with UEF < 3.45 or a natural gas, propane, or fuel oil water heater
  - ENERGY STAR electric dryer, CEF 3.93
    - Applies if existing dryer uses natural gas or propane
  - Electric induction cooktop and electric oven
    - Applies if existing range uses natural gas or propane
  - Electric pool heater
    - Applies if existing pool heater uses natural gas
  - Electric spa heater
    - Applies if existing spa heater uses natural gas.

## **Measure Package 16: Envelope Only - Light Touch Envelope**

### *Summary*

- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH50 for dwelling units with greater than 10 ACH50

### *Technical Description*

- Attic floor insulation
  - Applies only to dwelling units with vented attics
  - Value: R-30
    - Applies to IECC 2004 climate zone 1A
    - Applies to dwelling units without insulation or with insulation less than R-30
  - Value: R-49
    - Applies to IECC 2004 climate zone 2A, 2B, 3A, 3B, 3C
    - Applies to dwelling units without insulation or with insulation less than R-49
  - Value: R-60
    - Applies to IECC 2004 climate zone 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A, 7B
    - Applies to dwelling units without insulation or with insulation less than R-60
- Air leakage reduction
  - Value: 30% whole-home reduction in ACH50
    - Applies to all dwelling units with greater than 10 ACH50 infiltration.

## **3. Outputs**

### **3.1. Carbon Emissions**

Four sets of carbon emission impact results are included in this dataset release. These carbon emission results are not available in the data viewer’s graphical interface or customizable timeseries data downloads, but are present in the metadata annual results, individual dwelling model timeseries files, and pre-aggregated timeseries files (e.g., timeseries for a geography available on the OEDI data repository [[AMY2018](#), [TMY3](#)]).

#### ***Carbon Emissions Associated With On-Site Fossil Fuel Combustion***

For calculating carbon emissions related to the on-site consumption of natural gas, propane, and fuel oil, this dataset uses emission factor values from Table 7.1.2(1) of draft PDS-01 of [BSR/RESNET/ICCC 301 Addendum B, CO<sub>2</sub> Index](#). These values include both combustion and pre-combustion (e.g., methane leakage from natural gas) CO<sub>2</sub>e (carbon dioxide equivalent) emissions:

- 147.3 lb/MMBtu (228.5 kg/MWh) for natural gas
- 177.8 lb/MMBtu (275.8 kg/MWh) for propane
- 195.9 lb/MMBtu (303.9 kg/MWh) for fuel oil.

#### ***Carbon Emissions Associated With Electricity Consumption***

For CO<sub>2</sub>e emissions from changes in electricity consumption in buildings, this dataset incorporates long-run marginal emission factors from NREL’s [Cambium 2022 database](#). It is recommended to compare multiple standard scenarios to understand the range of potential

emission outcomes from changes in electricity consumption. Table 2 briefly describes the standard scenarios used in this dataset.

Table 2. Description of Carbon Emission Scenarios

NREL Standard Scenario	Start Year	Levelization Period (3% Discount Rate)
MidCase	2025	15 years
LowRECost	2025	15 years
HighRECost	2025	15 years
MidCase	2025	25 years

The NREL Standard Scenarios represent potential futures of the electric grid; we include three of those scenarios—Low Renewable Energy Cost (LowRECost), Mid-Case, and High Renewable Energy Cost (HighRECost). The emissions values represent a single year of emissions—these emissions are represented as a weighted-average year over the levelization period. The average is weighted toward years closer to the start year through the discount rate. Each emissions factor is applied at the Generation Emission Assessment Region geographic region (Section 5.11).<sup>6</sup>

Information on the Standard Scenarios used in this dataset can be found in the Cambium 2022 Standard Scenarios Report.<sup>7</sup> Cambium data can be viewed using NREL’s [Cambium Scenario Viewer](#).

### 3.2. Utility Bill Calculations

Utility bill calculations for this dataset use the same methodology used in the 2024.1 dataset.<sup>8</sup> A summary of this methodology is below.

Utility costs are calculated by using ResStock energy consumption results, fixed customer costs, and state-average volumetric costs from EIA. When possible, specific energy rates should be used to calculate utility bills instead of the pre-calculated bills provided based on state-averaged rates.

#### Residential Electricity Bills

We used data from NREL’s [Utility Rate Database](#) obtained in November 2021 to calculate the customer-weighted average fixed monthly electricity charge across all utilities in the database:

<sup>6</sup> Gagnon, Pieter, Will Frazier, Wesley Cole, and Elaine Hale. 2021. *Cambium Documentation: Version 2021*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-81611. <https://www.nrel.gov/docs/fy22osti/81611.pdf>

<sup>7</sup> Gagnon, Pieter, Maxwell Brown, Dan Steinberg, and Patrick Brown. 2023. *2022 Standard Scenarios Report: A U.S. Electricity Sector Outlook*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-84327. <https://www.nrel.gov/docs/fy23osti/84327.pdf>

<sup>8</sup> Present, Elaina, Philip R. White, Chioke Harris, Rajendra Adhikari, Yingli Lou, Lixi Liu, Anthony Fontanini, Christopher Moreno, Joseph Robertson, and Jeff Maguire. 2024. *ResStock Dataset 2024.1 Documentation*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-88109. <https://www.nrel.gov/docs/fy24osti/88109.pdf>



Equation 1. Customer-weighted average fixed monthly electric charge

$$\text{Fixed cost} = \frac{\sum \text{Fixed electric charge} * \text{Number of customers}}{\sum \text{Number of customers}}$$

This came out to approximately \$10/customer/month, or \$120/customer/year.

We obtained 2022 EIA [state average residential electricity data](#) including total revenue (in thousands of dollars), total sales (in MWh), and total customers (quantity). We then calculated the average variable electricity rate for each state as:

Equation 2. Average variable electricity rate

$$\text{Variable electric rate} = \frac{\text{Total revenue} - (\text{Fixed cost} * \text{Number of customers})}{\text{Total sales}}$$

This resulted in a per-unit residential utility customer rate for each state that varied from \$0.10/kWh in Washington to \$0.23/kWh in Maine.

The full year electricity bill was then calculated for each modeled dwelling unit using its modeled electricity consumption and the variable electric rate calculated for each state, as:

Equation 3. Full year electricity bill

$$\text{Full year electricity bill} = \$120 + (\text{Electricity consumption} * \text{Variable electric rate})$$

### **Residential Natural Gas Bills**

For natural gas bill calculations, we used the American Gas Association's value of \$11.25/customer/month<sup>9</sup> for the fixed portion of the utility bill (generally referred to as the "customer charge"). We obtained 2022 EIA data by state on [price](#), [consumption](#), and [number of customers](#), then calculated the volumetric rate for each state as:

Equation 4. Volumetric natural gas rate

$$\text{Volumetric natural gas rate} = \frac{(\text{Consumption} * \text{Price}) - (\text{Fixed cost} * \text{Number of customers})}{\text{Total sales}}$$

The results ranged from \$0.49/therm in Idaho to \$1.64/therm in Florida.

The full year natural gas bill was then calculated for each modeled dwelling unit using its modeled natural gas consumption and the volumetric natural gas rate calculated for each state as:

Equation 5. Full year natural gas bill

$$\text{Full year natural gas bill} = \$135 + (\text{Natural gas consumption} * \text{Volumetric natural gas rate})$$

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<sup>9</sup> American Gas Association. 2015. *Natural Gas Utility Rate Structure: The Customer Charge Component – 2015 Update*. Washington, DC. EA 2015-03. [https://www.ourenergypolicy.org/wp-content/uploads/2016/01/ea\\_2015-03\\_customercharge2015.pdf](https://www.ourenergypolicy.org/wp-content/uploads/2016/01/ea_2015-03_customercharge2015.pdf)

Dwelling unit models without natural gas consumption have no natural gas bill in our results, including no customer cost, whether in the baseline or because a measure package resulted in the elimination of all natural gas consumption.

### ***Residential Propane and Residential Fuel Oil Bills***

We obtained weekly volumetric rate data for the 2021–2022 winter from EIA for [residential fuel oil](#) and [residential propane](#), and averaged the data over the available weeks. When state-level data were not available, we used data from the state’s Petroleum Administration for Defense Districts (PADD) region. When the PADD region data were not available, we used U.S. national average values. These values ranged from \$1.79/gallon in Idaho to \$4.50 in Florida for propane and from \$2.54 in Nebraska to \$3.31 in Delaware for fuel oil. We then calculated propane and fuel oil bills by multiplying the fuel consumption for each dwelling unit model by the volumetric rate for that fuel and state.

### **3.3. Energy Burden**

We calculate energy burden as the ratio of full-year energy bills to full-year income. For the full-year energy bill, we use the energy bill outputs calculated as described in Section 3.2. For the full-year income, we needed to convert the ResStock income field, which is a range or bin, into a single numeric value per dwelling unit. This new field is expressly for the purpose of calculating energy burden and is called `representative_income`.

To determine the `representative_income` value the team created a series of lookup tables derived from 2019 5-years American Community Survey data<sup>10</sup>. The lookup tables provide the weighted median income within a specific set of characteristics: income bin, occupants, FPL, tenure, building type, and different geographic resolutions starting with the intersection of PUMA and county. The `representative_income` value is then assigned to each dwelling sample by matching the characteristics in the lookup table. The conversion starts with the highest geographic resolution lookup and moves to the next highest resolution if the lookup value set is missing until all dwelling samples have a numeric income assigned.

Vacant dwelling units are not assigned an income bin in the ResStock workflow. As a result, their `representative_income` is assigned as zero. Mathematically, this would lead to “undefined” energy burden for vacant units. In order to avoid values of “undefined” in the dataset, the energy burden field for vacant units is filled instead with locational averages based on county, if available, or otherwise based on state.

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<sup>10</sup> The `representative_income`, along with the income bins, is in 2019 USD whereas the utility bill is calculated using nominal rates from more recent years (2021-2022). If preferred it is possible to convert either the `representative_income` or the utility bill to the same real dollar before calculating energy burden. Without conversion, the real dollar amounts are misaligned by a few years. However the change in energy burden in the default calculations pre- and post-upgrade can provide a relative measure of improvement regardless of real dollar alignment.

## 4. Important Notes

### 4.1. Heat Pump Modeling

#### *Backup Heating and Capacity Retention Fractions*

Four of the five heat pump models in this dataset’s measure packages include supplemental backup heating—only the geothermal heat pump does not include backup heating. For measure packages 1, 2, 3, 6, 7, 8, 11, 12, and 13 this supplemental backup heating is electric resistance. For measure packages 4, 9, and 14 this supplemental backup heating utilizes the existing heating system from the baseline dwelling model. For the electric resistance backup heating and non-furnace existing system backup heating, the backup system will turn on when the heat pump cannot meet the full heating load. For heat pumps with furnaces that act as the backup heating system, the heat pump compressor is locked out when outdoor temperatures fall below 5°F and the furnace is locked out when outdoor temperatures go above 40°F. The backup furnace will turn on when the heat pump cannot meet the heating load and the outdoor temperature is between 5°F and 40°F.

The air-to-air heat pumps in this dataset have capacity retention fraction values determined at an outdoor temperature of 5°F. The capacity fraction is the percentage of the rated size of the heat pump that can be utilized at the specified outdoor temperature. A higher capacity fraction will reduce the heat pump’s rated size, allowing for a smaller sized unit, especially in cold climates—hence the “cold-climate” designation for the heat pump specified in measure package 2. The tradeoff for these heat pumps is that to maintain the rated HSPF1 and a high capacity retention fraction, the COP at low temperatures will be less than a unit with the same HSPF1 and a lower capacity retention fraction.

#### *Heat Pump Sizing*

The heat pumps in this dataset use two different sizing methodologies. The ducted ENERGY STAR air-to-air heat pumps are sized to ACCA Manuals S and J.<sup>11</sup> All other heat pumps are sized to the maximum load (i.e., “Max Load”) between the heating and cooling load of the dwelling unit. ACCA Manuals S and J size heat pumps to the cooling load with some allowed oversizing factors. For high heating loads and single-stage heat pumps (e.g., this dataset’s ENERGY STAR air-to-air heat pump), a 15% oversizing allowance applies. For dwellings in cold and dry climates, heat pump sizing is allowed an extra ton of refrigeration. For variable speed air-to-air heat pumps, a 30% oversizing allowance applies.

#### *Duct Sizing Limitations for Heat Pump Retrofits*

This dataset’s ducted heat pump measure packages represent a retrofit of a housing unit with an existing duct system. In a typical retrofit, this would mean the duct system size does not change during the heat pump installation. There is a limitation within ResStock that does not reflect this unchanging duct size when HVAC equipment retrofits are installed. In ResStock, the duct system size and maximum airflow rates will change according to requirements of the heat pump installation.

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<sup>11</sup> 2016 Manual J (8<sup>th</sup> edition) and 2014 Manual S (2<sup>nd</sup> edition)

## HVAC Equipment Rating Systems

ResStock currently uses legacy ratings—HSPF1 and SEER1 (or HSPF and SEER)—to identify the performance level of HVAC equipment, as shown in Section 2.2. These ratings were replaced by the U.S. Department of Energy with the current ratings—HSPF2 and SEER2, respectively—which are used to rate and specify the performance of most HVAC equipment<sup>12</sup> from 2023 onward. The performance values given in Section 2.2 are converted to the current rating system in Table 3.

Table 3. Measure Package Converted Heat Pump Rated Performance<sup>13</sup>

Measure Package	System Type	SEER2	HSPF2
1, 4, 6, 9, 11, 14	ASHP	15.2	7.8
	MSHP	16	8.3
2, 7, 12	ASHP	19	9.4
	MSHP	20	9.9
3, 8, 13	ASHP	22.8	11.1
	MSHP	24	11.7
5, 10, 15	GHP <sup>a</sup>	-	-

<sup>a</sup> Geothermal heat pump

## 4.2. Other Modeling Assumptions

### IECC Climate Zone Definitions and Attic Insulation

This dataset uses the 2004 IECC climate zone definitions rather than the definitions released in 2021. This causes some dwelling units to receive higher attic insulation levels in the Light Touch envelope package than they would have if 2021 definitions were used. Namely, dwelling units with lower attic insulation levels in counties that were redefined from climate zone 2A to 1A received R-49 instead of the IECC 2021 specified R-30 insulation. Similarly, dwelling units with lower attic insulation levels in counties that were redefined from climate zone 4 to 3 received R-60 instead of the IECC 2021 specified R-49.

### Exclusion of Some Shared HVAC System Dwellings and High-Rise Dwellings

All high-rise dwelling units with shared HVAC systems do not have any of this dataset's measure packages applied. High-rise dwellings with shared HVAC systems typically have unique HVAC designs, and it is likely that special accommodations would have to be made for retrofits similar to this dataset's measure packages. Additionally, no dwelling units with shared HVAC receive geothermal heat pump measure packages, ducted air-to-air variable speed heat pump measure packages, or the ENERGY STAR air-to-air heat pump with existing system as backup measure packages.

<sup>12</sup> Geothermal heat pumps are rated by EER.

<sup>13</sup> Calculated using conversion factors in Table 4.4.4.1(1) in [MINHERS Addendum 71f: SEER2 and HSPF2 Conversions](#)

### 4.3. Data Sources and Availability

ResStock only sources data from national or regionally representative vetted sources. If there has not been a national or regional survey on a topic or residential housing characteristic, ResStock cannot include it. Key ResStock data sources can be found in Table 2 of Wilson et al.<sup>14</sup>

Examples of topics that are not included or are poorly represented in this dataset due to data availability limitations include, but are not limited to:

- Housing in Alaska, Hawaii, the U.S. territories, Tribal lands, HUD/Section 8 housing, manufactured housing/mobile homes, and rural areas
- Structural or energy performance-related maintenance that must be completed before energy efficiency or electrification upgrades can take place; for example, addressing health and safety concerns, electrical panel upgrades, or housing rehabilitation.

### 4.4. Quality Assurance and Quality Control

The baseline and measure package annual and timeseries results were reviewed by subject matter experts at NREL over four stages in the dataset's development according to our quality control and quality assurance plan:

- The core 2024.2 dataset upgrade definition file was reviewed by multiple members of the ResStock team, ensuring correct applicability of all measure packages as described in Section 2.
- Results from a small-scale (500-dwelling model baseline) simulation of the measure packages in this dataset were reviewed by multiple members of the ResStock team. Attention was paid to applicability numbers, energy savings, emissions savings, and bill savings for each measure package.
- Results from a medium-scale (30,000-dwelling model baseline) simulation of this dataset was reviewed by multiple members of the ResStock team. The depth and breadth of this review was greater than the small-scale review. Total annual savings values—including energy savings, electricity savings, natural gas savings, propane savings, and fuel oil savings—were compared across all measure packages and baselines. Heating consumption savings for all abovementioned fuels were compared, including heat pump backup heating values. Similarly, cooling and water heating savings were checked. Key metrics for heat pump measure packages were analyzed as well, including heating/cooling system size, heating/cooling load, and unmet heating/cooling hours. All comparisons were analyzed both nationwide and by characteristic cross-sections (e.g., by climate zone, heating type, cooling type). Timeseries analysis across measure packages was performed and load shapes were compared for both summer and winter peak days. These peak days were analyzed nationwide as well as on an Independent System Operator/Regional Transmission Organization and climate zone basis.

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<sup>14</sup> Wilson, Eric J.H., Andrew Parker, Anthony Fontanini, Elaina Present, Janet L. Reyna, Rajendra Adhikari, Carlo Bianchi, et al. 2022. *End-Use Load Profiles for the U.S. Building Stock*. Washington, DC: U.S. Department of Energy. <https://www.nrel.gov/docs/fy22osti/80889.pdf>

- Heat pump COP curves as a function of outdoor temperature were examined. For ASHPs the curves were inspected to ensure the heat pump models were comparing well to the [NEEP Cold Climate Air Source Heat Pump List](#) data. For geothermal heat pumps, the curves were investigated to ensure that the assumed constant deep ground temperature was respected. These curves were investigated using IECC climate zone aggregate timeseries in cold climates (climate zones 6 and 7). The colder temperatures of climate zones 6 and 7 allow for the range of the curves to be extracted down to -15°F. For the ASHP models, the curves were investigated with and without the heat pump backup heating and fan energy. It was found that the lower rated heat pumps had a worse performance at lower temperatures, as expected. For ASHPs, the COP degradation as a function of outdoor temperature roughly matched representative units in the NEEP Cold Climate Air Source Heat Pump List data.
- Results from the production-scale (550,000-dwelling model baseline) simulation were compared to the results in the medium-scale simulation, both annual and timeseries, as well as any valid comparison points from recently published datasets (e.g., the 2024.1 release).

Due to the size and complexity of the data in this release, not every data point or possible aggregation of data was reviewed independently by NREL. Errors may exist and we encourage dataset users to contact us at [ResStock@nrel.gov](mailto:ResStock@nrel.gov) should they encounter any problems.

## 5. Questions This Dataset Can and Cannot Answer

### *Analysis Questions That Can Be Answered*

These are the type of questions that can be answered via data processing, distillation, and visualization of this dataset.

1. Housing makeup and current snapshot of energy consumption
  - How many homes are heated by electricity versus gas? How leaky or well insulated are these homes?
  - How prevalent is one housing type or vintage versus another? What are the differences in their energy consumption?
  - How are low-income and renter-occupied housing different from other housing units?
  - What are the fuel types and end uses that provide the largest opportunities for efficiency and electrification?
2. Technology potentials and what-if scenarios
  - What is the range of savings per dwelling unit if measure packages X, Y, or Z are implemented? What are the total expected savings for a program or community from those measure packages?
  - What are the energy, carbon, and utility bill impacts of envelope improvements versus heat pumps with electric backup or existing heating as backup versus combinations of envelope and heat pump measures?

- What are the long-term carbon emissions implications of electrification based on different potential futures for the electric grid, as represented by different Cambium emission factors?
3. Addressable questions with timeseries and customization
- Does residential electrification shift a region from summer-peaking to winter-peaking?
  - What is the total change in peak demand from electrification or efficiency measures?
  - How do higher efficiency equipment or envelope improvements with equipment upgrades affect the change in peak demand?
  - What are the bill impacts of different measures under state average utility rates?

### ***Out-of-Scope Questions That Cannot Be Answered With ResStock Alone***

These are questions that ResStock data do not provide out-of-the-box answers to as they require additional research or data to contextualize the ResStock results. For example, ResStock does not reference any policies or provide the relevance of measures to rebates and incentives. It is up to the users to understand the details of these programs and identify relevant ResStock data to find answers.

4. Questions that cannot be answered with ResStock alone
- What is the potential for energy demand response in a region? What is the potential for rooftop or community solar to help offset residential consumption and bills?
  - Given a program budget, what are the tradeoffs between an efficiency program that prioritizes low-income households compared to a business-as-usual scenario where no specific households are targeted or prioritized?
  - How many homes can qualify for Weatherization Assistance Program (WAP) based on federal poverty level, and what savings are available from WAP-qualified measures?
  - How many homes can qualify for Inflation Reduction Act Section 50122 rebates based on area median income, how many rebates can they leverage, and what are their potential savings from measure packages X, Y, or Z?
  - Can appliance replacements alone qualify homeowners for Inflation Reduction Act Section 50121 whole-home performance-based rebates?
  - How might different income groups leverage financing mechanisms, such as “pay as you save,” or rebates from federal, state, or local programs, to make their energy retrofits more cost-effective?
  - Do utility bill savings change under a time-of-use electricity rate?

## **6. Other ResStock Resources**

Here are some other ways you can learn about ResStock, and if you have specific questions reach out to our team at [ResStock@nrel.gov](mailto:ResStock@nrel.gov). While ResStock focuses on residential buildings, there is a similar tool called ComStock™ that focuses on commercial buildings. Check out the ComStock website if you have questions or want to explore information about commercial buildings.

**ResStock Website:** <https://resstock.nrel.gov/>

**ResStock Documentation:** <https://resstock.readthedocs.io/en/latest/index.html>

**ResStock and ComStock YouTube Training Series:**

[https://www.youtube.com/playlist?list=PLmIn8Hncs7bEYCLIMATE\\_ZONEiHaoPSovoBrRGR-tRS](https://www.youtube.com/playlist?list=PLmIn8Hncs7bEYCLIMATE_ZONEiHaoPSovoBrRGR-tRS)

**Highlighted Publications:** <https://resstock.nrel.gov/page/publications>

**ComStock website:** <https://comstock.nrel.gov/>