ResStock Technical Reference Documentation, Active Development Version

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ResStock 2025 Release 1, October 2025

1 Executive Summary

What Is ResStock?

ResStock^{TM} is the best-in-class building stock energy model for simulating and publishing energy use, utility bills, and greenhouse gas emissions from the residential sector of the United States. ResStock answers two primary questions: (1) How and when is energy used in the U.S. residential building stock? and (2) What are the impacts of technological and behavioral changes in U.S. homes? Specifically, ResStock quantifies energy use at high granularity, while maintaining heterogeneity, across geographical locations, demographic groups, home types, fuels, end uses, and time of day. Additionally, it details the impact of efficiency, technology fuel changes, or energy flexibility measures: total changes in the amount of energy used by measure; where or in what use cases upgrade measures save energy; when or at what times of day savings occur; and which building stock or demographic segments have the biggest savings potential. This model, and the public datasets it produces, are foundational to identifying pathways to affordable and resilient energy use in the U.S. residential buildings sector.

Motivation

The primary objective of ResStock is to empower decision makers to make data-driven choices to improve energy affordability, comfort, and resilience in the U.S. housing sector. Across the United States, increasing numbers of cities, counties, and states are setting goals around energy use and associated metrics. Although much of this planning rightfully focuses on the electric grid, the on-site combustion of fossil fuels in U.S. homes, primarily for space and water heating, accounts for 56% of on-site energy usage. Furthermore, pathways to improving the resiliency and reliability of the electric grid are highly dependent upon the future timing and magnitude of electricity demand. Buildings currently comprise 74% of electricity demand in the United States (U.S. Energy Information Administration 2023), and this could grow with electric vehicle adoption. Much of the work in supporting grid resiliency through building sector demand will fall on state and local government staff, the engineering and policy consulting communities, and advocacy and research organizations to ensure that these goals are realistic, achievable, and distributed appropriately. ResStock was developed by the National Renewable Energy Laboratory (NREL) with funding from the U.S. Department of Energy (DOE) to assist the professionals and researchers tasked with implementing these initiatives.

How Is ResStock Accessed?

The ResStock model and its published datasets are foundational for a wide range of stakeholders. Professionals and researchers have several pathways for using ResStock data and insights. They can review published fact sheets and reports based upon ResStock data. They can use a web-based visualization platform to interact with the dataset of annual and timeseries results, or they can use a simple spreadsheet-type analysis to interact with annual energy consumption results and aggregated timeseries load profiles. If users want to go deeper, they can even use the raw simulation results dataset, which may require big-data skills and cloud or high-performance computing assets.

Impact

In 2024-25, The ResStock Data Viewer for the public data was accessed across all 50 U.S. states, by more than 2,000 unique users who queried the data on average 16 times per user. The queries mainly support consultants, utilities, city, county, and local governments, state offices, DOE, and other federal offices. It is estimated that the datasets that ResStock produces are used by utilities that deliver over half of all US electric sales. The combined ResStock and ComStock datasets contributed to over $2 billion dollars worth of industry project revenue. Cumulatively, the datasets have been downloaded over 45 million times, making it the most downloaded dataset across the Open Energy Data Initiative's (OEDI) 2,976 datasets.

Purpose of This Document

The purpose of this document is to provide a central technical reference of the ResStock baseline. ResStock is a complex model with code spread across multiple repositories. The goal is to provide the central theory and arguments in a single location with clear references to underlying models and software for users who need additional detail.

2 Acknowledgments

Since initial development over a decade ago, ResStock has had dozens of researchers contribute to the structure, features, theory, and publication of data. In particular, we'd like to acknowledge Craig Christensen, who was instrumental in the initial model development. Additionally, we'd like to acknowledge our peer reviewers on this document: Andrew Parker and Jon Winkler. Additionally, we'd like to acknowledge U.S. Department of Energy (DOE) staff who have supported and guided ResStock development, including Dale Hoffmeyer, Amir Roth, Gretchen Maia, Asa Foss, Amy Royden-Bloom, and Eric Werling of the Building Technologies Office; Joan Glickman of the Office of State and Community Energy Programs; John Agan, Jenah Zweig, and Erin Boyd of the Office of Policy; and Robert Weber of the Bonneville Power Administration. Additionally, ResStock has been improved upon through work for parties outside of DOE, most notably the Los Angeles Department of Water and Power. We also would like to acknowledge the work of the EnergyPlus® whole-building energy modeling tool, the OpenStudio® SDK, and the OpenStudio-HPXML schema implementation, which provide the foundational model underpinnings of energy simulation in ResStock and which are the result of years of hard work by many people across DOE, the national laboratories, and the private sector.

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A portion of this research was performed using computational resources sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy and located at the National Renewable Energy Laboratory.

3 Version History

Technical Reference Documentation	Standard Data Release	ResStock
Draft, ResStock 2025 Release 1, October 2025	2025 Release 1	`sdr_2025_Release_1`
v3.3.0, July 2025	2024.2	v3.3.0

Technical Reference Documentation	BuildStock Batch	OpenStudio-HPXML
Draft, ResStock 2025 Release 1, October 2025	ResStock SDR 2025 Release 1	v1.10.0
v3.3.0, July 2025	v2023.10.0	v1.8.1

4 List of Acronyms

ACCA Air Conditioning Contractors of America

ACH air changes per hour

ACS American Community Survey

AFUE Annual Fuel Utilization Efficiency

AIANNH American Indian/Alaska Native/Native Hawaiian

AMY Actual Meteorological Year

ASHP air-source heat pump

ATUS American Time Use Survey

AWS Amazon Web Services

CBSA Core-Based Statistical Area

CEC California Energy Commission

CEER combined energy efficiency ratio

CFL compact florescent bulb

CFM cubic feet per minute

COP coefficient of performance

CRAK Custom Region Alaska

CRHI Custom Region Hawaii

DOE U.S. Department of Energy

EER energy efficiency ratio

EF Energy Factor

EIA U.S. Energy Information Administration

EPW EnergyPlus Weather file

EV Electric vehicle

FPL federal poverty level

GEA Generation and Emissions Assessment

HERS Home Energy Rating System

HIFLD Homeland Infrastructure Foundation-Level Data

HPC high-performance computing

HSPF Heating Seasonal Performance Factor

HVAC heating, ventilating, and air conditioning

LBNL Lawrence Berkeley National Laboratory

LED light-emitting diode

LIHEAP Low-Income Home Energy Assistance Program

MELS Miscellaneous Electric Loads

MF multifamily

MSA Metropolitan Statistical Area

MSHP mini-split heat pump

NEEA Northwest Energy Efficiency Alliance

NFRC National Fenestration Rating Council

NHTS National Household Travel Survey

NREL National Renewable Energy Laboratory

OEDI Open Energy Dataset Initiative

PADD Petroleum Administration for Defense District

PUMA Public Use Microdata Area

PUMS Public Use Microdata Samples

PV photovoltaic

RBSA Residential Building Stock Assessment

RECS Residential Energy Consumption Survey

ResDB Residential Diagnostics Database

SEER Seasonal Energy Efficiency Ratio

SFA single-family attached

SFD single-family detached

SUV sport utility vehicle

TEMPO Transportation Energy & Mobility Pathway Options Model

TMY Typical Meteorological Year

URDB Utility Rate Database

WWR window-to-wall ratio

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5 Introduction

ResStock^{TM} is the foundational national residential building stock energy model for the United States. ResStock is a highly granular, bottom-up, physics-based model that uses best-available data sources on American housing, statistical sampling methods, and advanced building energy simulations in EnergyPlus® to model the annual subhourly energy consumption of the residential building stock across the United States with high spatial granularity. ResStock's companion model, ComStock, covers the commercial building stock of the United States.

Many of the internal workings of these models are distinct, but the results and types of analyses that can be done with them are similar. Documentation for ComStock can be found on the ComStock website.

ResStock represents all types of housing units, including single-family, multifamily, and manufactured or mobile homes. The definition of the residential sector follows the U.S. Energy Information Administration's (EIA) definition of *housing unit* and therefore does not include dormitories, prisons, assisted care facilities, and other congregate housing situations, but does include high-rise multifamily buildings that are sometimes considered commercial buildings for the purpose of building codes (U.S. Energy Information Administration 2024b).

This report serves as the primary documentation of the methodology and assumptions of ResStock. It is updated with each ResStock software release or ResStock standard data release.

5.1 Overview and Primary Use Applications

ResStock answers two primary questions: (1) How and when is energy used in the U.S. residential building stock? and (2) What are the impacts of technological and behavioral changes in U.S. homes? Specifically, ResStock quantifies energy use across geographical locations, demographic groups, building types, fuels, end uses, and time of day. Additionally, it details the impact of efficiency, fuel changes, or flexibility measures: total changes in the amount of energy used by measure; where or in what use cases efficiency or technology change measures save energy; when or at what times of day savings occur; and which building stock or demographic segments have the biggest savings potential.

This type of building stock energy model can be conducted using a range of approaches, varying on a spectrum from simple representation and fast execution or complex representation and slow execution. Each approach has benefits and trade-offs. The National Energy Modeling System used by the EIA is an example of a simple, fast method. This system models the entire U.S. energy system at the census region level, and its results for the building stock have low spatial, temporal, and subsector granularity. On the other hand, modeling each individual building within the building stock is an example of a complex, slow method. This approach is impossible to implement in practice due to the lack of building-level data necessary to develop the model, and can lead to false confidence in results if not underpinned by appropriate data. Additionally, if appropriate data did exist and the model could be developed, this approach would offer a high granularity of results, but would provide more detail than needed for most applications and would be highly impractical to update or run frequently.

The ResStock approach is positioned between these two extremes, providing highly granular housing stock data to capture the diversity of housing and occupants while maintaining a usable execution speed. Three advantages of the ResStock approach are: (1) subhourly detail; (2) modeling of upgrade measure interaction, controls, and demand flexibility; and (3) the ability to post-process the data to slice results (e.g., by location, household income, fuel types, building size) and extract a wide array of insights from the simulations, including distributional impacts—how costs and benefits are distributed across different groups of households. This approach strikes a balance by presenting enough information to answer its two driving questions while remaining computationally tractable.

Professionals and researchers have several pathways for using ResStock data and insights. They can review published fact sheets and reports based upon ResStock data, query a web-based visualization platform to view annual and timeseries results, or use a simple spreadsheet-type analysis to investigate annual energy consumption results and aggregated timeseries load profiles. If users want to go deeper, they can use the raw simulation results dataset, which requires comfort dealing with large datasets and potentially cloud or high-performance computing assets. All of these approaches to using ResStock are supported by the ResStock team, which can be contacted at resstock@nrel.gov. Because all ResStock inputs are publicly available, it is also theoretically possible for users to run ResStock themselves using their own computing resources and weather files. However, the ResStock team is not able to provide support for external users running ResStock software because of the significant burden it would impose on staff time and budget. We encourage users to use the publicly released datasets, visualizations, and analysis products that receive rigorous review for quality assurance and control.

5.2 ResStock Calibration and Validation

Calibration and validation have been core components of ResStock since its inception. In 2014, initial validation efforts focused on comparing estimates of average annual electricity and gas use per home to EIA Residential Energy Consumption Survey (RECS) 2009 microdata for cohorts of single-family detached homes grouped by combinations of region, vintage, and fuel type (see Section 2.6 in Wilson et al. 2017). Visual comparisons of cumulative distribution functions for energy use, along with Kolmogorov–Smirnov tests for goodness of fit, were used to validate heterogeneity in model outputs. In 2015, the initial year-long calibration effort involved 12 rounds of model structure and input modifications to improve agreement with RECS 2009 data. Examples of these modifications include: adding new data sources for probability distributions, changing dependencies for housing characteristic probability distributions, changing the number of probability distribution options, and reducing the number of weather locations (to allow additional granularity in other areas).

Calibration and validation efforts expanded to include hourly timeseries outputs in 2019–2022. As part of a three-year U.S. Department of Energy (DOE)-funded project, we compared ResStock results to data from a wide range of sources such as utility load research data, advanced metering infrastructure data, and end-use submetered data to inform modeling improvements, and validated the updated model. ComStock also went through this process as part of the same project. These data sources, as well as the comparison plots and accompanying discussion, are described in detail in that project's final report (Wilson et al. 2022). Since the publication of that report, additional modifications have been made to ResStock. These ongoing modifications are documented in this report.

5.3 ResStock Data Access

Access to ResStock data is provided in multiple formats. The current state of data access changes periodically and is maintained at the National Renewable Energy Laboratory (NREL) ResStock website.

6 ResStock Workflow

In this section, we provide details of the major components of ResStock's modeling workflow.

6.1 Overview

ResStock is an interconnected set of modeling assumptions, workflows, and published datasets within the software ecosystem of DOE's flagship building energy modeling software EnergyPlus, OpenStudio, and OpenStudio-HPXML. EnergyPlus is open-source software used to simulate the physics-based energy performance of individual buildings, including heating, cooling, lighting, appliances, and ventilation systems. It is widely used by engineers and architects to simulate, optimize, and evaluate building designs for energy efficiency, fuel changes, and comfort. EnergyPlus is the building energy simulation engine that ultimately performs physics-based simulations within ResStock. OpenStudio is an open-source software development kit that allows for programmatic creation and management of building energy models in EnergyPlus. It simplifies the process of simulating building energy performance through software automation, making it easier for users to simulate and interact with the building energy model and results. OpenStudio-HPXML (OS-HPXML) is a tool that bridges the OpenStudio platform with the Home Performance XML (HPXML) data standard, enabling accurate and consistent modeling and simulation of residential building energy performance. It automates the process of creating HPXML files, which describe residential building characteristics commonly used during energy audits, and converts them into EnergyPlus-compatible models, facilitating the evaluation of energy efficiency measures in homes. This OS-HPXML foundation makes ResStock compatible with other software within the residential modeling ecosystem such as BEopt^{TM}, Home Energy Score^{TM}, URBANopt^{TM}, and OCHRE^{TM}. On top of the core building energy modeling, ResStock adds a synthesized U.S. housing stock and demographic characterization, batch processing of a large number of EnergyPlus models, and post-processing workflows to add emissions, utility cost, and energy burden data. The housing building stock characterization sits on top of EnergyPlus, OpenStudio, and OpenStudio-HPXML to automate the creation, simulation, and processing of the representative building energy models generated through this characterization, and a large database of published simulation results from the stock model.

ResStock is an archetype-based building stock model of the U.S. residential building stock and is classified as a Q4 physics-simulation model by the building stock energy model classification framework (Langevin et al. 2020). The model has five major steps (Figure 1): (1)Stock Characterization, (2) Sampling, (3) Building Energy Model Articulation, (4) Batch Simulation, and (5) Results and Publication. The next few subsections briefly introduce each of these topics.

6.2 Stock Characterization

ResStock characterizes the U.S. residential building stock and the associated occupants using a probabilistic representation of building and household characteristics developed using the best available data. Much of the underlying data for the U.S. residential stock comes from national survey data. These surveys include the U.S. Census, the Public Use Microdata Sample (a microdata version of the American Community Survey [ACS]), the American Housing Survey (AHS), and the EIA's Residential Energy Consumption Survey (RECS). These surveys provided weighted survey samples with different building characteristics (for example: heating fuel, vintage, number of occupants, floor area, etc.) that ResStock leverages.

ResStock takes this survey microdata, processes it, and connects it to other surveys to develop housing characteristic probability distributions.

Some of these characteristics include the location of the housing unit (examples: state, county, climate zone), the geometry of the housing unit (examples: building type, foundation type, floor area, number of floors), the envelope information (examples: wall insulation, attic type, window panes), appliances (examples: age of refrigerator, heating fuel of the cooking range, whether the unit has in-unit laundry), heating ventilating and air-conditioning (HVAC) system (examples: heating system type, cooling system type, setpoint temperatures, whether the housing unit has ducts), water heating (examples: water heating fuel, type of water heater), household information (examples: income, number of occupants, and tenure). ResStock only contains discrete distributions, and even continuous variables like vintage or floor area are discretized into bins. A given discrete bin of the distributions is referred to as an "option" of

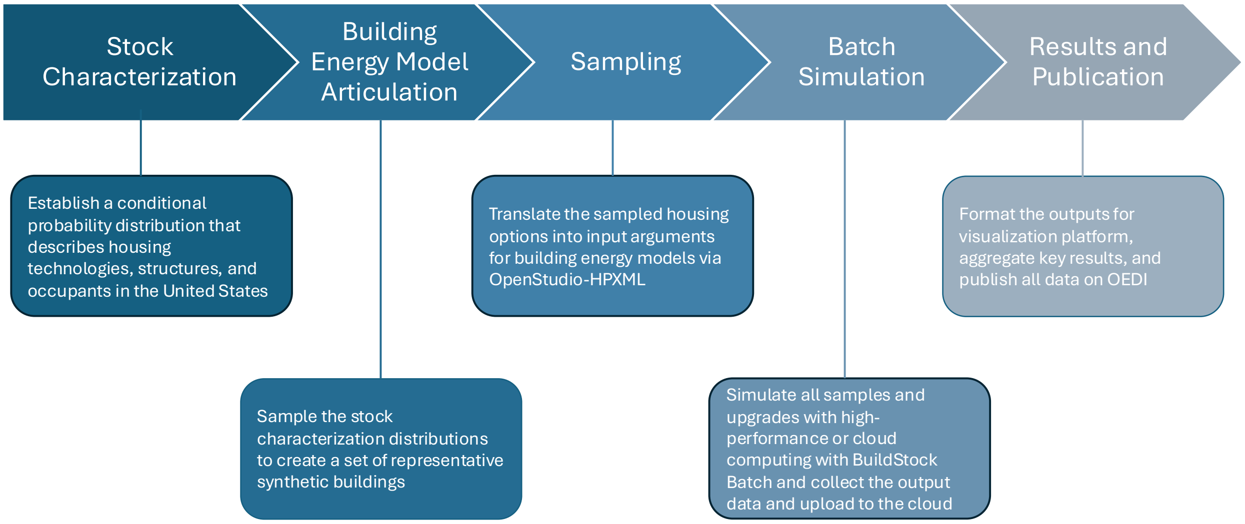


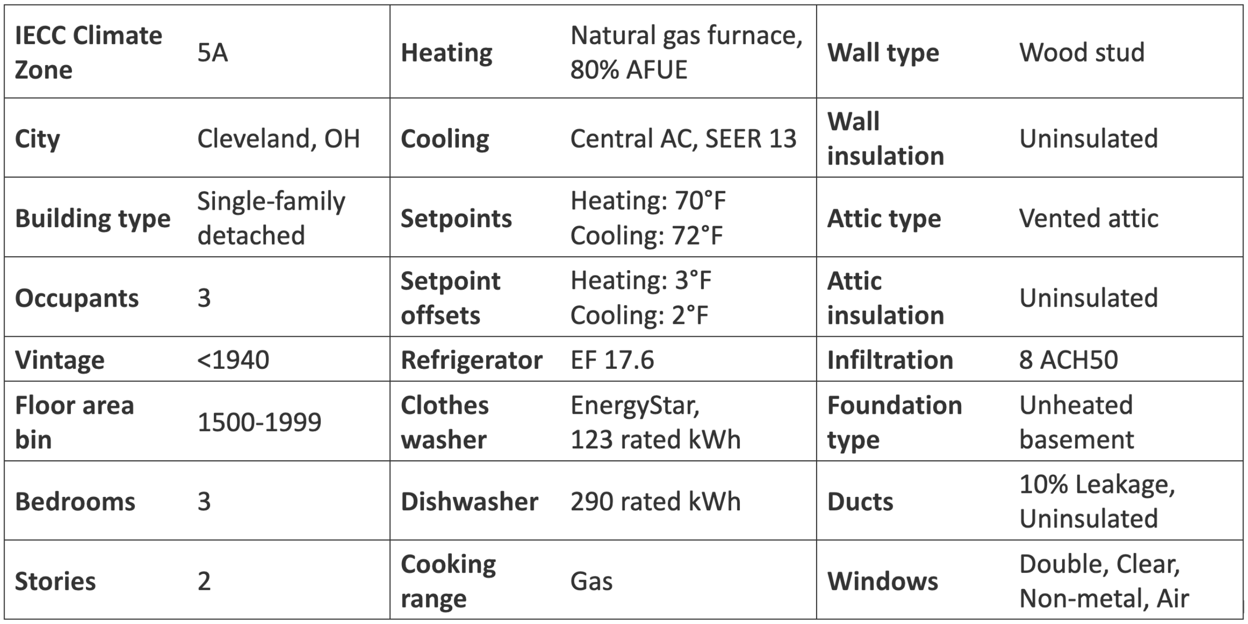
Figure 1. A high-level overview of the ResStock workflow steps and what occurs during those steps

the characteristic. For example, in the Foundation Type characteristic, there is an option for the unit to have an "unheated basement" and another option for the unit to have a "heated basement." Another example is that the Geometry Floor Area characteristic has an option for a housing unit to have a floor area between 1,000 and 14,999 ft^2.

The input distributions also capture important correlations between building characteristics, sometimes referred to as conditional dependencies. For example, in Los Angeles, CA, in the 1960s, many residential buildings were constructed, while other cities may have seen growth at different periods. This is captured in ResStock by making the Vintage characteristic conditionally dependent on the location of the housing unit, so different locations will have different distributions of housing age. Another example is that energy codes became more widespread in the late 1970s, causing minimum insulation values in new homes to increase. This relationship is captured by making the Insulation characteristics, like wall insulation, conditionally dependent on vintage. Through these correlations taken from the survey data, a network of characteristics and conditional dependencies are assigned through ResStock characteristic variables. It is these conditional dependent distributions of the characteristics that create the residential building stock characterization in ResStock. Information about how these distributions are created can be found in Section 7.1. Detailed information about each characteristic, assumptions, dependencies, and data sources can be found in Section 8.

6.3 Sampling

ResStock does not model actual buildings (for example: the apartment complex at 123 Main Street). Instead, the housing characteristic distributions are sampled hundreds of thousands of times—typically 550,000—to create a synthetic stock representation of U.S. housing units. Each sampled housing unit is assigned an option for each of the ResStock housing characteristics. Within the ResStock workflow the full set of sampled housing units and their associated characteristics is referred to as the `buildstock.csv`. An illustrative example of some characteristics of a ResStock model is shown in Figure 2. More information about how the sampling is performed can be found in Section 7.3. Each of the 550,000 representative samples in the `buildstock.csv` can be thought of as an archetype residential housing unit description, meaning that each synthetic building represents approximately 250 real U.S. housing units.



IECC Climate Zone	5A	**Heating**	Natural gas furnace, 80% AFUE	**Wall type**	Wood stud
City	Cleveland, OH	**Cooling**	Central AC, SEER 13	**Wall insulation**	Uninsulated
Building type	Single-family detached	**Setpoints**	Heating: 70°F Cooling: 72°F	**Attic type**	Vented attic
Occupants	3	**Setpoint offsets**	Heating: 3°F Cooling: 2°F	**Attic insulation**	Uninsulated
Vintage	<1940	**Refrigerator**	EF 17.6	**Infiltration**	8 ACH50
Floor area bin	1500-1999	**Clothes washer**	EnergyStar, 123 rated kWh	**Foundation type**	Unheated basement
Bedrooms	3	**Dishwasher**	290 rated kWh	**Ducts**	10% Leakage, Uninsulated
Stories	2	**Cooking range**	Gas	**Windows**	Double, Clear, Non-metal, Air

Figure 2. An illustrative example of a representative housing unit sample from ResStock (does not show all characteristics available in ResStock)

6.4 Building Energy Model Articulation

After sampling is complete, the `buildstock.csv` file contains the synthetic housing stock, with each row representing a sampled housing unit and each column corresponding to a characteristics and the field within that column representing a sampled option. Each housing characteristic has an option assigned for each sampled housing unit in the synthetic stock. The table itself is a set of string values that need to be transformed into a building energy model for each sampled housing unit. The transformation of a single line of characteristic options (see Figure 2 for an example) into an EnergyPlus building energy model is referred to as the model articulation process.

ResStock can be run either just for "baseline" energy use—i.e., energy use in the present-day housing stock—or with "upgrades" that will simulate both the baseline as well as a technical potential of different technologies to change energy use and associated metrics. The foundation of each of these workflows is the model articulation process. This document discusses primarily the ResStock baseline state since each public data release of upgrade measures has its own accompanying detailed technical documentation.

The first step in the model articulation process maps the options for each housing characteristic within a single row of the `buildstock.csv` to ResStock modeling arguments. For reference, the mapping is specified in the options_lookup.tsv file. This file contains all the housing characteristics and all the housing characteristic options in the ResStock national residential stock characterization and the associated ResStock model arguments. This file also includes housing characteristic options that are not sampled in the ResStock baseline, but which could be applied as upgrade options. A list and description of all the ResStock arguments can be found on the ResStock GitHub Repository. For ResStock to model any option, either in baseline or in upgrade, that option must exist as a `characteristic | option` pair in the associated *options_lookup.tsv*. For example, if there exists a pair *Windows|Double, Clear, Non-metal, Air*, that is then available for use in the baseline housing stock distributions and in upgrade specifications in the project specification file. A `characteristic | option` pair does not need to exist in the baseline to be used in an upgrade. The technical details associated with each option of the housing characteristics are defined in the options_lookup.tsv file. For example, the wall exterior finish option: Wood, Medium/Dark is translated into a medium dark color wood siding with an exterior finish R-value of 1.4 in the ResStock measure, which is transformed into other model file inputs. While the ResStock housing characterization provides many inputs that ultimately make up a building model sample (see Section 6.4 for model articulation), it's important to recognize that there are far more technical details that are not characterized by ResStock, e.g., how much windows are being shaded, how much natural ventilation is used over the course of the year. Instead, these parameters assume the default values from OS-HPXML. For more details on modeling assumptions, refer to the OS-HPXML documentation and Section 8 on how building systems are modeled.

Many housing characteristic options are directly used in the creation of the EnergyPlus models, but some are just structural in developing the probability distributions. For example, the ASHRAE IECC Climate Zone 2004 characteristics set the `site_iecc_zone` and `site_type` ResStock arguments (Section 8.1.2), but Location Region is just used as a dependency to define other characteristics that impact the energy modeling. Housing characteristics that do not assign an argument are called meta-parameters, for example Federal Poverty Level. These meta-parameters are often used as intermediate dependencies in other characteristics to separate key housing characteristics that influence the energy simulation. For example, the Federal Poverty Level characteristic and options are used to correlate income to appliance ownership and efficiency. The options and arguments for each ResStock housing characteristic are discussed in detail in Section 8.

6.4.1 OpenStudio–HPXML

The next step in the workflow is converting ResStock arguments to the OpenStudio-HPXML arguments to create the HPXML file. OpenStudio-HPXML uses a series of OpenStudio measures to generate an EnergyPlus model for each sample based on the building and occupant characteristics defined by ResStock (Figure 3). In many cases, ResStock relies upon the OpenStudio-HPXML default arguments and calculations. The OpenStudio measures called in the workflow are:

- **BuildExistingModel** – meta-measure that calls on all following measures in the workflow and passes in ResStock files
- **ResStockArguments** – translates housing characteristics from ResStock into arguments for BuildResidentialHPXML
- **BuildResidentialHPXML** – creates the HPXML file for ResStock sample and calculates defaults if not provided from ResStock
- **BuildResidentialScheduleFile** – generates schedules and references the `schedules.csv` from the HPXML file
- **ApplyUpgrade** – meta-measure that calls the following measures in the workflow to modify arguments for samples that have upgrade scenarios applied.
- **HPXMLtoOpenStudio** – translation of the HPXML file to an OpenStudio model.

Throughout this translation process, in most cases, the ResStock arguments are the same as the final OpenStudio-HPXML arguments assigned in BuildResidentialHPXML. An example of an identical argument is `geometry_unit_num_bedrooms`. However, there are some instances where the ResStock arguments intentionally differ from the OpenStudio-HPXML arguments and need further adjustment. Another potential difference is combining and modifying ResStock arguments into one OpenStudio-HPXML argument. An example is using `air_leakage_percent_reduction` as part of an envelope upgrade that reduces infiltration. In this scenario, the `air_leakage_value` is adjusted by the `air_leakage_percent_reduction` argument.

6.4.2 Post OpenStudio–HPXML modifications

After the OpenStudio-HPXML files are returned, there is a final step before the OpenStudio and EnergyPlus model is simulated. The `ResStockArgumentsPostHPXML` measure is executed. This measure provides an opportunity to modify the returned OpenStudio–HPXML files before simulation. Currently, this measure is not used for the baseline stock. An example use of this measure would be modeling a schedule modification for demand flexibility during an upgrade.

6.5 Batch Simulation

The model articulation process discussed in the previous sections is performed for each of the 550,000 ResStock samples; when factoring in upgrade scenarios, this can result in tens of millions of EnergyPlus simulations. The NREL-developed software BuildStock Batch manages the various stages of the workflow of running ResStock or ComStock. BuildStock Batch has its own documentation for a detailed understanding of the software. BuildStock

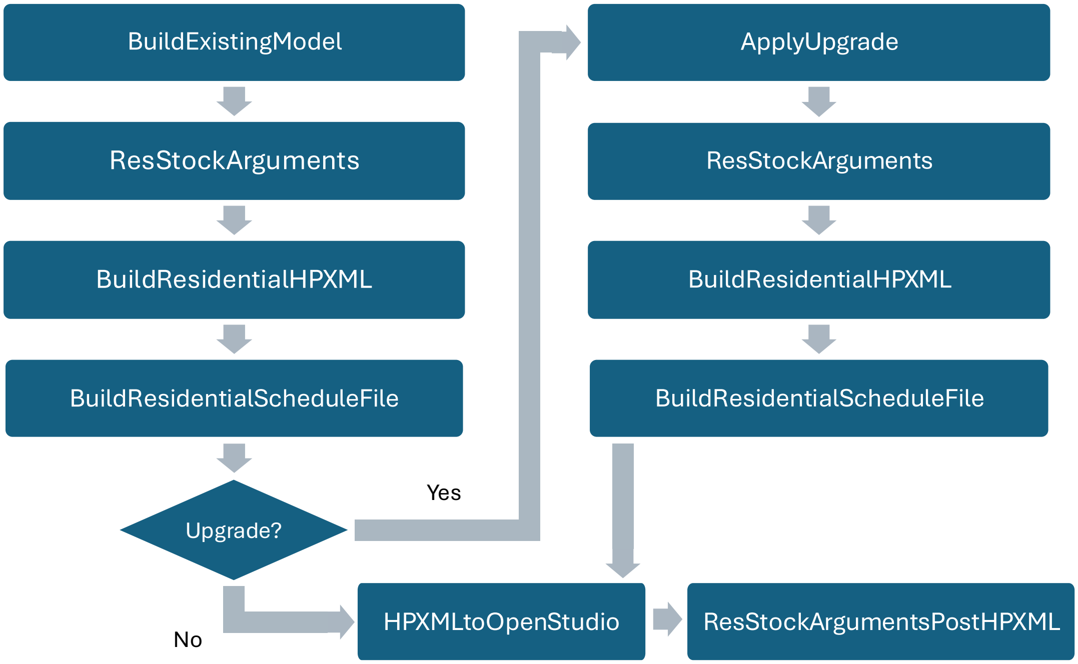


Figure 3. Flowchart of OpenStudio measures performed to translate a ResStock sample into an OpenStudio model

Batch can be run locally, on NREL's high-performance computing (HPC) system, or on the cloud using Amazon Web Services (AWS) or Google Cloud Platform. The local version of BuildStock Batch is mainly used for testing purposes during new feature development and for use in the continuous integration of the ResStock and ComStock software stack. The local version is not used for production-scale runs due to the typically low number of CPU cores and limited memory of local machines. The HPC- or cloud-based workflows can be used to run the full set of baseline samples and upgrade simulations, but all public runs up through 2024 have been completed on NREL's HPC system.

BuildStock Batch is initialized with a project file that configures all the inputs to the workflow. An example project file to simulate the national baseline stock can be found in the ResStock repository. There are three major steps to the BuildStock Batch workflow: (1) sample creation and job setup, (2) parallel simulation of all baseline and upgrade simulations, and (3) collection of output data from the simulations and upload to AWS for querying. The sampling and job setup process creates the sampled description of the housing characteristics in the "buildstock.csv" file. Then BuildStock Batch submits a job that runs all the simulations in parallel by performing the model articulation and the EnergyPlus simulation for each sample. To run these simulations efficiently, BuildStock Batch communicates with the computing nodes to manage the computing resources at every stage of the workflow. In particular, the software facilitates the simulations in batches by breaking them up into smaller jobs that can be run by parallel processors or by multiple nodes in a distributed manner. This is critical for enabling large-scale simulations which are often time- and memory-intensive to process. BuildStock Batch makes it possible to run hundreds of thousands of simulations in a timely manner by leveraging HPC. After the simulation completes for each model, the workflow post-processes the simulation output by compiling them into annual summary files and coalescing the timeseries into partitioned files separated by upgrade scenario and other user-specified characteristics such as state and county. As the final step, BuildStock Batch can optionally upload the result files to AWS S3 storage, where they can be queried much like a database using web services such as AWS Athena.

A successful run of 550,000 samples with no upgrades, a 15-minute time step, no errors, and no queue time can typically be run on NREL's HPC system within a few hours and creates about 500 GB of output.

6.5.1 Upgrade Specification

In ResStock, most of the details of upgrade specification occur directly in the project file under the upgrades key, using fields from the `options_lookup.tsv` file specified in logic blocks. Options specified for upgrades include which segment of the baseline the upgrade should be applied to, cost multipliers, and the “reference” case, which is important if doing a comparison against a business-as-usual scenario (especially for costs). If the upgrades section is not specified, only the building stock baseline will be simulated. Details of the upgrades associated with each ResStock data release can be found in the supporting upgrade measure documentation.

ResStock upgrades are deterministic, not probabilistic. You can specify, for example, that all housing units with a specific existing air conditioner in baseline get a specific new air conditioner in upgrade. Or you can use more complex logic and specify 10 different air conditioners in upgrade, based on any characteristic or combination of characteristics. But each housing unit will deterministically receive a specific new air conditioner based on the logic. This can cause challenges. One example is if specifying a new air conditioner for housing units that don’t already have air conditioning, you might ideally specify a new, probabilistic range of cooling setpoints for those homes. However, this is not possible. This is why ResStock specifies cooling setpoints for every housing unit, whether or not the unit has air conditioning: so that if an upgrade run assigns air conditioning to that housing unit, the resulting setpoints are appropriately diverse. One can think of this situation as the housing unit’s preference of a cooling setpoint if one had a cooling system. There are several other similar parameter option specifications in baseline that are not used to model the baseline but are available in case of certain upgrade option assignments.

6.6 Results and Publication

The results from the BuildStock Batch post-processing include: (1) metadata and annual results (referred to as the `results.csv` file), (2) a set of end-use timeseries parquet files that combine all the end-use timeseries results from the 550,000 models, and (3) a compressed set of building simulation folders with the results of the OpenStudio-HPXML workflow for each building sample. The `results.csv` file includes the housing characteristics and annual energy, emissions, utility bills, and cost multipliers for each of the 550,000 models. When a production run of ResStock is completed, reviewed, and ready for publication, the outputs are then reformatted so that each building timeseries is a single file, the result columns start with “in.<input>” and “out.<output>” (instead of “build_existing_model” and “simulation_output_report,” the original outputs of OpenStudio-HPXML), and the energy results are all converted to kWh. This extra step is done in part for readability and ease of use, and also because the ResStock dataset viewer allows all the energy outputs to be stacked on top of one another and expects the new naming convention. This step is also done outside of the BuildStock Batch workflow. After the conversion, the datasets are uploaded to the Open Energy Dataset Initiative End-Use Load Profiles submission.

7 Input Structure and Sampling

In this section, we discuss the structure of ResStock's input data and our sampling approach. This includes an overview of the probability theory behind ResStock's inputs, how we merge data sources, and how stochastic occupant schedules are created.

7.1 Overview of Housing Characteristics

ResStock uses a set of conditional distributions to describe the characteristics of U.S. housing units and the households living in them. There are over 150 characteristics described in ResStock, the majority of which describe the physical attributes of the buildings. Some demographic household characteristics are also included as inputs, both to describe the demographics of the households (e.g., income and renter/owner status) as well as to differentiate key appliance ownership and building characteristic differences that exist between households of different demographics. Each sample in ResStock represents one housing unit (as opposed to a building with many housing units) and will have a value selected for every input housing characteristic defined in ResStock.

Table 1 is an illustrative example of a conditional distribution table for the housing characteristic Water Heating Fuel. There are three parts to this table—options, dependencies, and sampling probability. The options are the values a characteristic parameter can take on (e.g., water heater fuel has the options: electricity, fuel oil, natural gas, other fuel, and propane). If one characteristic is described based on another, this is known as a dependency. The dependencies explain how the characteristic is distributed (e.g., Water Heater Fuel saturation varies based on Geometry Building Type RECS, Heating Fuel, and State). Since all buildings must receive a value assigned for a Water Heating Fuel option during sampling, the probabilities in the option columns are equal to one when summed row-wise. Each row gives the parameter distribution within a housing segment defined by the dependencies. For example, the Water Heating Fuel for Mobile Homes with a Heating Fuel of Electricity located in CA has a 72.37% probability of being Electricity, and a 17.59% probability of being Natural Gas. The *sampling_probability* column provides the likelihood of sampling a home with the dependency characteristics, i.e., the relative size of the housing segment in the United States. The column can be extended with the option probability (i.e., each value under the option column) to give the joint probability of sampling the characteristics of both the dependencies and the option. For example, Mobile Homes with a Heating Fuel of Electricity located in CA represent 0.09022% of the national residential housing units. Multiplying this by the 72.37% probability of these housing units having Electricity as their Water Heating Fuel, we determine that Mobile Homes with a Heating Fuel of Electricity located in CA and having a Water Heating Fuel of Electricity represent 0.06529% of the national residential housing stock.

7.2 Methods for Creating Housing Characteristic Distributions

ResStock housing characteristics are mostly compiled using publicly available survey data. Major data sources include the Residential Energy Consumption Surveys (RECS) from the EIA (U.S. Energy Information Administration 2020), the Public Use Microdata Samples (PUMS) of the American Community Survey (Ruggles et al. 2022), and the American Housing Survey (U.S. Census 2022). For certain characteristics that are not yet surveyed nationally, region-specific datasets are used instead. For example, the hot water fixture distribution is informed by field data from a demand management program in the Northeast. Roof insulation, ceiling insulation, and window area characterization come from the Residential Building Stock Assessments by the Northwest Energy Efficiency Alliance (Northwest Energy Efficiency Alliance 2024). Some housing characteristic distributions are created manually as they do not have any survey data to base on, with about a quarter of ResStock's housing characteristics being constructed using reference numbers from studies. For example, the insulation level for ceilings and walls are derived from the Home Innovation Research Labs 1982–2007 data, and spot ventilation for bathroom and range hood comes from the Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014). Ten characteristics are

Dependency=Geometry Building Type RECS	Dependency= Heating Fuel	Dependency= State	Option= Electricity	Option= Fuel Oil	Option= Natural Gas	Option= Other Fuel	Option= Propane	sampling _probability
Mobile Home	Electricity	CA	0.7237	0	0.1759	0	0.1005	0.0009022
Multifamily with 2–4 Units	Electricity	CA	0.6379	0	0.3621	0	0	0.0026521
Multifamily with 5+ Units	Electricity	CA	0.5690	0	0.4217	0	0.0093	0.0113951
Single-Family Attached	Electricity	CA	0.6986	0	0.2696	0	0.0318	0.0019855
Single-Family Detached	Electricity	CA	0.3200	0	0.6428	0	0.0372	0.0107185

Table 1. Subset of Water Heating Fuel distribution

created based on engineering judgment, including things like door area, plug load diversity, and mechanical ventilation. Each input housing characteristic to ResStock is discussed in detail in Section 8, including data sources and assumptions.

ResStock updates housing characteristic distributions to the latest release of longitudinal surveys whenever possible and incorporates new data sources when a need and a data source are both identified. The housing characteristics captured in ResStock 2025 Release 1 represent the existing U.S. housing stock as of approximately 2019 (housing stock: ~2019, weather: 2018 or TMY3, and appliances: ~2020). ResStock models all 50 states and the District of Columbia. ResStock does not currently model U.S. territories such as Puerto Rico or Guam.

To generate a housing characteristic's distribution, we generate distributions as normalized cross tabulations of the variables and their dependencies using the sample weight in the source data. We select dependencies from the available variables in the surveys based on a combination of engineering judgment, empirical evidence of correlation, and the need to balance between data fidelity and variability. For example, we know there is likely to be a relationship between having natural gas as a space heating fuel and having natural gas as a water heating fuel since there is already natural gas service to the home, so we set Heating Fuel as a dependency for Water Heating Fuel. Engineering judgment can help pre-select a set of variables to correlate with the parameter. The correlation is then verified with empirical evidence that may include correlation matrices, statistical tests, and plots or tabulations that demonstrate the significance of dependency variables in the output distributions. Input characteristics are constantly being evaluated and updated as better data are identified.

To ensure data fidelity and representativeness, each row in a distribution is generally informed by at least 10 samples in the source data. The number of dependencies to include is limited by the size of the source data, since the data will be sliced over many parameters to generate each row of the distribution. For example, smaller source datasets can afford to split over fewer or less granular dependencies before the data is spread too thin. In such cases, it becomes necessary to choose variables that best capture the variability in the parameter. To do this, we use graph theory and Bayesian inference to calculate the incremental information gain by each candidate variable, which ranks them for selection. Sometimes the dependency selection is further limited to keep the distribution to a manageable file size for workflow purposes. For example, a distribution with a dependency on County will likely have few other dependencies, as doing so will result in an oversized distribution that cannot be stored in the GitHub repository and is otherwise difficult to work with since there are over 3,100 counties in the United States.

In addition to strategic dependency selection, ResStock has two other approaches for dealing with low samples or missing dimensionality in the source data: fallback rules for dimensional coarsening and dimensional blending. Some characteristics in ResStock have several granularity options available, e.g., Vintage (housing unit age grouped into 10 bins) vs. Vintage ACS (housing unit age grouped into 6 bins). These granularity options help bridge between source data that have different native resolutions to connect the derived distributions. They are also used in fallback rules and dimensional coarsening to address low samples. A common practice in ResStock is to fill the cross tabulation using the native resolution of the dependency variables. Then where there's insufficient sample count, ResStock pulls the distribution from higher granularity variables to fill the rows. For example, state-level tabulation can be used to fill or supplement the rows with low samples that are natively at the county level. This dimensional coarsening may result in some rows sharing similar probability distributions but at the benefit of filled data gaps and higher sample confidence. The fallback rules are what define these processing sequences so that some or all dependency variables can be coarsened incrementally until all rows reach enough samples. Dimensional coarsening is commonly done over geography, climate zone, vintage, building type, floor area, and income by grouping together similar options or options believed to influence energy consumption similarly (e.g., neighboring geographies). In Section 8 we discuss in the assumptions section for each variable if dimensional coarsening is used.

Another approach to dealing with low samples or missing dimensionality is dimensional blending. This simply refers to updating one distribution with another distribution, hence "blending" the two distributions together. Dimensional blending is often used when a distribution lacks the desired granularity natively and is therefore augmented by another distribution with that granularity. For example, the windows distribution in ResStock comes from RECS, which characterizes the windows based on glass type and frame material. To augment the window options to account for storm window and low-e glazing, the distribution is re-normalized using proportionalities derived from shipment data.

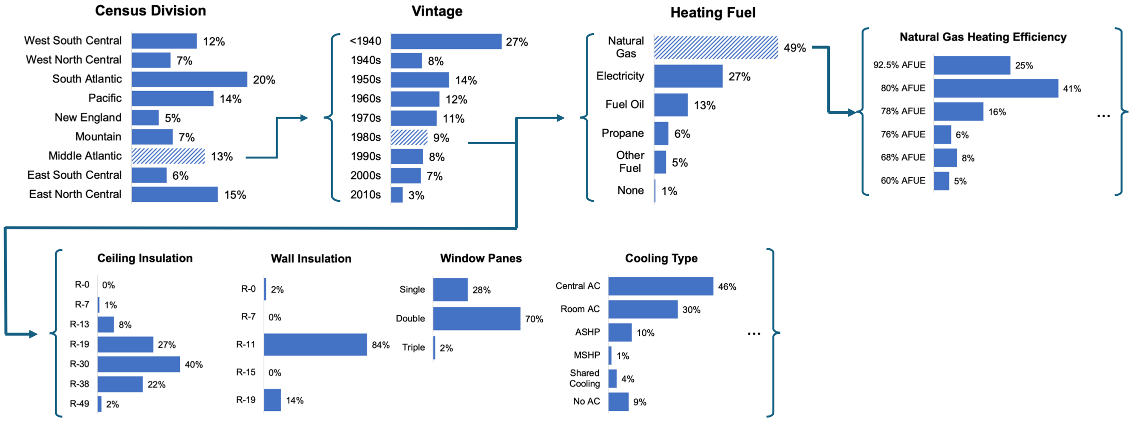


Figure 4. Example of interconnected building characteristic distributions

The full cross-tabulation of a parameter and its dependencies can sometimes give rise to impossible or highly improbable combinations of characteristics, e.g., single-family houses that are over 8 stories tall. These combinations are assigned a parameter value of “void,” and prune rules are used in the distribution development to ensure that such combination will never be sampled. If such combination is accidentally sampled (perhaps due to error in upstream housing characteristics), then this will be caught immediately since “voids” are supposed to be un-sample-able. Some characteristic combinations are realistic but may be pruned due to limitations in the upstream modeling workflow. For example, in ResStock, single-family detached houses that are 0–1,499 ft^2 with attached garages can currently only have a single-car garage. This is due to ResStock assuming a specific aspect ratio for building footprint and modeling constraints restricting that the garage cannot be larger or deeper than the livable space.

Many of the housing characteristic distributions are validated by comparing their marginal distribution by each dependency with those of the source data. This is to ensure that any special handling of the data to address low samples or missing dimensionality does not deviate the distributions significantly from the source data. The parity maintained with the source data also means the housing characterization in ResStock inherits the same level of survey biases or uncertainty as those that exist in the source datasets. For example, ResStock’s characterization of Mobile Homes has higher uncertainty than any other housing types as mobile homes are the least common of the major housing types (single-family, multifamily 2–4 units, etc.), and fewer data points exist for them in the source datasets. While using the survey sample weight to construct the distributions helps ensure they are representative of the U.S. housing stock, ResStock does compare the effect of using different types of sample weight when they are available in certain surveys, such as RECS.

7.3 Sampling Methodology

With the full conditional probability network of inputs defined, ResStock samples the inputs to create the synthetic housing stock. The input file structure and dependency network determine the order in which each characteristic is sampled. Sampling starts with housing features that have no dependencies and next moves to characteristics that have dependencies on the first level of characteristics sampled. This process proceeds until all inputs are sampled and defined. For example, Figure 4 shows an example set of housing characteristic distributions that are interconnected by dependencies. To create a building model in this hypothetical network, the census division is sampled first (and Middle Atlantic is chosen). Then the vintage of the model is sampled based on the distribution of vintage for the chosen census division (1980s is chosen). Next, the heating fuel is sampled according to the distribution for the chosen vintage (natural gas is chosen), and this process repeats until all housing characteristics are determined.

To create a full representative synthetic housing stock for the United States, ResStock employs quota-based sampling. In quota-based sampling, building models are created until the specified number of samples (i.e., the quota) is reached. Sampling starts with the most likely characteristics or most common housing unit in the United States, and then continues filling out increasingly less-likely combinations of characteristics until the quota is reached. This approach creates building models with equal sample weight, meaning each sampled housing unit represents the same number of housing units in the real housing stock. This is a product of quota-based sampling where the likelihood of a building characteristic is directly reflected in the number of times that characteristic is sampled instead of being included in the sample weight.

The quota-based sampling approach is different from purely random sampling (e.g., Monte Carlo) where the samples can come from anywhere in the distributions. Random samples thus may not be representative until many samples are drawn. In quota-based sampling, the quota is multiplied by the probability distributions to determine how many samples will have certain characteristics. If natural gas accounts for 50% of space heating in the marginal distribution, then one in two samples will be decidedly heated by gas, and this holds true for a quota of two or a quota of a million. However, larger quotas are required to sample uncommon characteristics due to the discretization effect (i.e., a characteristic of 0.1% probability will not show up in a sampling quota of 500 as 0.1%*500 = 0.5, which is less than one sample). It is worth noting that the characteristics do not need to be uncommon at the national scale for this problem to occur. Even if a characteristic has 1% probability nationwide, we will not get the expected 0.01 * 550,000 = 5,500 samples in a national run and in fact may get zero samples if the characteristic has dependencies that will cause it to be sampled within thousands of slices of (quota of) less than 100 samples. While such extreme cases are uncommon, most characteristics do have biases on their national-scale saturation over what one would expect based on the housing characteristic distribution due to this quirk of quota sampling.

While the diversity in the samples scales with quota in both sampling methods, the rate of reaching a reasonable diversity or converging to the population mean is much faster for quota-based sampling than random sampling. The convergence rate is proportional to the square-root of the quota for quota-based and to the quota for random sampling. The ability to sample for characteristics proportional to their distributions makes quota-based sampling effective as the representativeness of the sampled stock is better maintained even at smaller sampling quotas.

For public datasets, different versions of ResStock runs will by default have different samples. Building model ID 1 is not the same between published datasets.

7.4 Schedule Creation

In addition to the housing characteristic input files, occupant and energy use schedules are another major necessary building energy model input. Most ResStock schedules are also based upon survey data, but we use a different approach for generating these schedule files since they need to be temporally comprehensive (typically covering a full year with 15-minute time steps) as well as sufficiently diverse to appropriately represent the range of load shapes that occur within the housing stock as well as the aggregate total.

In ResStock, schedules are used to define a variety of building system operations (Table 2). For example, the space heating and cooling system maintains the indoor air temperature according to a detailed schedule of heating and cooling setpoint temperatures. Interior lighting turns on according to occupancy, while exterior lighting is set to turn on at a specific time frame between the evening and the early morning. These schedules represent either preset equipment schedules, typical usage patterns, or the stochastic time use behaviors of all occupants living within a household. Occupant-driven schedules are typically heterogeneous to represent a diversity of behaviors and preferences. Many of the schedules capture not only the timing of use but also the intensity of use as fractional values, with diversity for every day of the year. These fractional value timeseries are then multiplied by the annual end-use energy or hot water use (calculated separately according to building simulation standards such as ANSI/RESNET/ICC 301 standard or those developed by Hendron and Engebrecht 2010 and Wilson, Engebrecht Metzger, et al. 2014) to generate the respective end-use load profiles or hot water draw profiles. The schedules are modified for vacant units and vacancy periods (i.e., an occupied household goes on vacation). When a unit is unoccupied for either reason, all schedules are set to zero except for HVAC setpoint temperature schedules designed to keep pipes from freezing. See Section 8.11.3 for more information. In ResStock, schedules are generated either using a stochastic occupancy generator (inherited from OS-HPXML) or through more simplistic defined schedules.

Stochastic Schedules. ResStock uses a stochastic schedule generator to produce representative and heterogeneous schedules for occupancy and a number of appliances and hot water end uses. Developed using the American Time Use Survey (ATUS) data from 2013–2017, submetered appliance energy data, and a supplemental hot water model, the generator combines Markov chain and probability-sampling for schedule simulation. At a high level, the generator uses Markov chain models built from the ATUS data to produce occupant activity schedules for seven different activities: sleeping, personal hygiene, laundry, cooking, dish washing, absent, and active-at-home. These schedules are then processed and combined with appliance information to form household-level appliance and hot water

Schedule Name	Unit	Description	Stochastic?
`ceiling_fan`	frac	Ceiling fan energy use schedule	Stochastic
`clothes_dryer`	frac	Clothes dryer energy use schedule	Stochastic
`clothes_washer`	frac	Clothes washer energy use schedule	Stochastic
`cooking_range`	frac	Cooking range & oven energy use schedule	Stochastic
`cooling_setpoint`	deg F	Thermostat cooling setpoint schedule	Non-Stochastic
`dishwasher`	frac	Dishwasher energy use schedule	Stochastic
`electric_vehicle_charging`	frac	Availability schedule for electric vehicle charging.	Stochastic
`electric_vehicle_discharging`	frac	Availability schedule for electric vehicle discharging.	Stochastic
`extra_refrigerator`	frac	Non-primary refrigerator energy use schedule	Non-Stochastic
`freezer`	frac	Freezer energy use schedule	Non-Stochastic
`fuel_loads_grill`	frac	Grill fuel load energy use schedule	Non-Stochastic
`fuel_loads_lighting`	frac	Lighting fuel load energy use schedule	Non-Stochastic
`fuel_loads_fireplace`	frac	Fireplace fuel load energy use schedule	Non-Stochastic
`heating_setpoint`	deg F	Thermostat heating setpoint schedule	Non-Stochastic
`hot_tub_pump`	frac	Hot tub pump energy use schedule	Non-Stochastic
`hot_tub_heater`	frac	Hot tub heater energy use schedule	Non-Stochastic
`hot_water_clothes_washer`	frac	Clothes washer hot water use schedule	Stochastic
`hot_water_dishwasher`	frac	Dishwasher hot water use schedule	Stochastic
`hot_water_fixtures`	frac	Fixtures (sinks, showers, baths) hot water use schedule	Stochastic
`lighting_interior`	frac	Interior lighting energy use schedule	Stochastic
`lighting_exterior`	frac	Exterior lighting energy use schedule	Non-Stochastic
`lighting_garage`	frac	Garage lighting energy use schedule	Stochastic
`occupants`	frac	Occupant heat gain schedule	Stochastic
`plug_loads_other`	frac	Other plug load energy use schedule	Stochastic
`plug_loads_tv`	frac	Television plug load energy use schedule	Stochastic
`plug_loads_well_pump`	frac	Well pump plug load energy use schedule	Non-Stochastic
`pool_heater`	frac	Pool heater energy use schedule	Non-Stochastic
`pool_pump`	frac	Pool pump energy use schedule	Non-Stochastic
`refrigerator`	frac	Primary refrigerator energy use schedule	Non-Stochastic
`water_heater_setpoint`	deg F	Water heater setpoint schedule	Non-Stochastic
`water_heater_operating_mode`	0/1	Heat pump water heater operating mode schedule. 0=hybrid/auto, 1=heat pump only.	Non-Stochastic
`vacancy`	0/1	Vacancy schedule. 0=occupied, 1=vacant. Automatically overrides other columns.	Non-Stochastic

Table 2. Modeled schedules in ResStock

schedules. For example, both clothes washer and clothes dryer events are scheduled to occur during laundry activity, whereas sink events are scheduled to occur during active-at-home activity. More details of the stochastic occupant model can be found in Chen et al. (2022).

One of the housing characteristics in ResStock is the number of occupants (see Section 8.11.4 documentation). The generator starts by randomly assigning each occupant within a ResStock model to one of the four preset occupant types that roughly correspond to day-away-evening-home, day-away-evening-away, mostly-home-early-risers, mostly-home-late-risers. These preset occupant types were created by clustering the ATUS data and picking the number of clusters that provides a good balance between clustering performance and diversity of behavior. There is one Markov chain model for each occupant type and for weekday and weekend separately. Each Markov chain model is built from a cluster of respondents sharing a similar occupancy pattern and models their activity progression throughout the day using a time-inhomogeneous activity transition probability. This means what activity happens next depends on both the current activity and the time of day.

Once the appropriate Markov chain model is picked for an occupant, the schedule generation proceeds with sampling of the starting activity at midnight at the beginning of the weather year and sampling of activity at each time step based on the transition probability given the activity of the previous time step using the Markov-chain transition probability matrix. This process repeats until the full-year schedule is generated for each occupant in the household. Next, the occupant schedules are split into end uses and then merged as a household. The occupant schedules are combined for activities with shareable appliances (e.g., two or more occupants cooking at the same time is one cooking event) and aggregated for individualized activities (e.g., personal hygiene for each occupant is added together for hot water fixtures). While each occupant can only engage in one activity at a time, the activities can overlap after aggregating to the household level.

Next, the generator converts the household activity schedules into appliance power and hot water schedules. For laundry machines, dishwashers, and range ovens, the generator uses the activity schedules for onset only and samples separately for the duration and power consumption of the appliance, which comes from the 2011 Residential Building Stock Assessment Metering Study (RBSAM) by NEEA. For laundry, the dryer is modeled to start immediately after the washer. For appliance hot water, the activity schedules similarly provide the draw onset while the duration and flow rate are sampled using NREL's Domestic Hot Water Event Schedule Generator (Hendron, Burch, and Barker 2010). In this way, the hot water schedule and power schedule for the clothes washer and dishwasher are only aligned in terms of the onset and not necessarily the duration. This is consistent with real hot water appliance cycles in which hot water is drawn typically at the beginning. Once an appliance cycle completes with a minimum time gap, the generator finds the next activity onset from the activity schedules and the process repeats until all appliance schedules are created.

For hot water fixtures, sink use is based on the at-home inactive portion of the occupancy schedule while the personal hygiene schedule is split between shower and bath. For lighting, plug loads, and ceiling fans, circuit-level reference schedules are used and they are modulated by the occupancy schedule. This means the modulated schedule is the same as the reference schedule at 100% occupancy and ramps down to the minimum of the reference schedule at 0%. The lighting and plug loads reference schedules are taken from Wilson, Engebrecht Metzger, et al. (2014), and the ceiling fans' come from RBSAM.

The stochastic schedule generator produces all appliance schedules at 15-minute resolution and hot water schedules at 1-min to account for their shorter usage duration. These schedules are then aggregated to the simulation time step and then normalized so the maximum demand within a year is 1. The normalized schedules are multiplied by the annual energy or water consumption determined separately for their respective appliances to produce the end-use load profiles. A problem with this modeling approach is that the disconnect between energy calculation and schedule generation can result in unrealistic load profiles, which is especially important when looking at power consumption at shorter timescales. An end-use appliance with a large usage multiplier assigned can also be assigned a stochastic schedule with low usage, thus resulting in unusually large power draws in the simulation and vice versa. This problem is less jarring at the stock level as aggregation tends to balance and smooth out these anomalies. This is an area identified for future improvement.

Non-Stochastic Schedules. For non-stochastic schedules, ResStock defines various options for 24-hour setback periods (in 1-hour resolution) for HVAC heating and cooling setpoints in options_lookup. For range spot ventilation (see Section 8.4.9), the schedule is generated on the fly using inputs that specify the start hour and the number of hours in operation.

There are two types of OS-HPXML schedule input: simple schedule input or detailed schedule input. Simple schedule inputs are available as weekday/weekend fractions and monthly multipliers for a variety of building characteristics. Detailed schedule inputs allow schedule values for every hour or time step of the simulation. They can be used to reflect real-world or stochastic occupancy and must consist of a full year of data, even if the simulation is part-year. The schedule inputs do not need to have the same time resolution as the simulation. They can be more or less granular than the simulation time step. When schedules are not specified, the default OS-HPXML schedules are used. Default schedules can be simple or detailed and are typically smooth, averaged, hourly, and homogeneous schedules mostly derived from Building America House Simulation Protocols (Hendron and Engebrecht 2010, Wilson, Engebrecht Metzger, et al. 2014).

8 Housing Characteristics and Inputs

In this section, we overview each of the input housing characteristics for ResStock in detail including ResStock options, associated ResStock arguments, and the details of each of those arguments. In ResStock, each input characteristic gets its own input file. The full set of housing characteristic input files is available in the main ResStock GitHub repository in the project national folder. We discuss each of these input files as well as the general theory for how different systems and components are modeled. Within each section we also provide the national-level stock saturation of each option within a characteristic. These top-level saturations collapse much of the detail and nuance in ResStock's probability distributions, but the saturations serve to give a sense of how common different options are, generally, in the United States.

We organize this discussion by the major types of inputs: Geography, Geometry, Envelope, HVAC, Water Heating, Appliances, Lighting, Plug Loads, and Household characteristics. For each of these major sections, we discuss ResStock's approach to these input types, highlighting where it might vary from OS-HPXML. In the argument tables, a selection of "auto" means that the value is being calculated or defaulted in OS-HPXML. Additionally, we discuss weather inputs to ResStock, which is specified separately from the main input files.

8.1 Geography

ResStock provides a wide range of geographic inputs and outputs. These fields allow for detailed input probability distributions for the U.S. residential building stock characterization. These geography fields are also useful for aggregating and analyzing ResStock outputs.

All the geography fields are compiled into a geography lookup table that contains census block-level resolution. For reference, the Geography Hierarchy Diagram for Census geographies can be found on the Geography Hierarchy Diagram U.S. Census website. This diagram shows that the fundamental geography is a census block. All other census geographies stem from this definition. This hierarchy is used to create a lookup table for all geography characteristics in ResStock.

Added to this table are occupied and vacant unit counts for each census block from the 2020 U.S. Census Redistricting Data and ACS 5-year 2016 data. The ACS number of units is specified by census tract and downscaled to the census block level using the 2020 Redistricting data. The 2020 census block data are converted to 2010 census blocks using the National Historical Geographic Information System (NHGIS) Geographic Crosswalks. All the characteristics and distributions of housing characteristics are pivoted from this lookup table relating the geography definitions and housing unit counts. Also in this lookup file is the NHGIS GISJOIN codes that help join this file to other geography fields not in the lookup table or the ResStock outputs.

The ACS housing unit data are typically used by ResStock to specify in the project file the number of housing units in the United States. The ACS data are a 5-year average compared to the single-year 2020 Redistricting data. Consistency for using ACS for unit counts at the census geographies is also achieved except for the "City" characteristic. The City characteristic uses the downscaled data from the ACS to census block, because City boundaries are specified by census blocks.

The census geographies are set to be consistent with the U.S. Census Bureau's definitions as of July 1, 2015. The 2010 Census geography definitions and changes between the 2010 Census and July 1, 2015, can be found on the U.S. Census Bureau Decennial Census website.

When looking at the structure of the Geography dependencies, the ASHRAE IECC 2004 input file does not have any dependencies. ASHRAE IECC 2004 is the top-level geography characteristic. The reason this climate zone characteristic is first and not some U.S. Census characteristic is because of the way the ResStock Sampling algorithm works. By using the large climate zones, more uniformity is achieved in the spatial allocation of the samples. From ASHRAE IECC climate zone, the County and Public Use Microdata Area (PUMA) characteristic is assigned, placing the sample in the smallest resolution geographic characteristic. From here the other geographic characteristics are various aggregations of the County and PUMA field or larger geographies.

In discussing the Geography inputs to ResStock, we break it down into four subcategories: Census Geographies, Climate Zones, Grid and Emissions Geographies, and Other Geographies.

8.1.1 Census Geographies

This section contains ResStock characteristics based on the U.S. Census geographic definitions. There are 11 input files to ResStock that specify Census Geographies:

- Census Region
- Census Division
- State
- County
- PUMA
- County and PUMA
- Metropolitan and Micropolitan Statistical Area
- City
- American Indian/Alaska Native/Native Hawaiian (AIANNH) Area
- County Metro Status
- PUMA Metro Status.

Census Region

Description

The U.S. Census Region where the sample is located. The regions are a collection of U.S. Census Divisions.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.

Direct Conditional Dependencies

- Census Division.

Options

The options are the four U.S. Census Regions: Midwest, Northeast, South, and West.

Distribution Assumption(s)

No assumptions are made.

Census Division

Description

The U.S. Census Division where the sample is located. The regions are a collection of U.S. states.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.

Direct Conditional Dependencies

- State.

Options
The option are the U.S. Census divisions: East North Central, East South Central, Middle Atlantic, Mountain, New England, Pacific, South Atlantic, West North Central, and West South Central.

Distribution Assumption(s)
No assumptions are made.

State

Description
The U.S. state where the sample is located. In ResStock, States are defined by a collection of Counties.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.

Direct Conditional Dependencies

- County.

Options
The options for each State are the collection of postal abbreviations (e.g., AL, AK, AR). Each option sets the `site_state_code` argument. The `site_state_code` argument choices are also the State abbreviations. An example option and argument assignment for Alabama is as follows: the option name is AL and `site_state_code`=AL. The rest of the States follow this structure.

Table 3. The ResStock argument definitions for the State characteristic

Name	Required	Type	Choices	Description
`site_state_code`	false	Choice	auto, AK, AL, AR, AZ, CA, CO, CT, DC, DE, FL, GA, HI, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY	State code of the home address.

Distribution Assumption(s)
No assumptions are made.

County

Description
The U.S. County where the sample is located.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.

Direct Conditional Dependencies

- County and PUMA.

Options

The County characteristic options are structured using the State name and County name. An example of the option corresponding to Denver County in Colorado would be "CO, Denver County". The ResStock arguments `simulation_control_daylight_saving_enabled`, `site_zip_code`, `site_time_zone_utc_offset`, and `weather_station_epw_filepath` are not constant across all the County options.

The `simulation_control_daylight_saving_enabled` argument is set to "true" except in Arizona where all the counties are set to "false."

The `site_zip_code` argument is assigned by using a single zip code for the entire county.

The `site_time_zone_utc_offset` argument is assigned using the population centroid of each county. As time zones cut through counties, some units will have the wrong time zone. Since the population centroid is used, the bounding error for units being in the wrong counties is 50%.

The `weather_station_epw_filepath` argument is "../../../weather/<County GISJOIN>.epw" where <County GISJOIN> is the NHGIS GISJOIN value for the county. The NHGISJOIN for a county always starts with the letter "G" followed by the state's two-digit FIPS, a "0," and then the County 3-digit FIPS code. An example of this argument assignment for the option "CO, Denver County" is `weather_station_epw_filepath`=../../../weather/G0800310.epw.

Table 4. The ResStock argument definitions for the County characteristic

Name	Required	Units	Type	Choices	Description
`simulation_control_daylight_saving_enabled`	false		Boolean	auto, true, false	Whether to use daylight saving.
`site_zip_code`	false		String		Zip code of the home address.
`site_time_zone_utc_offset`	false	hr	Double	auto	Time zone UTC offset of the home address. Must be between -12 and 14.
`weather_station_epw_filepath`	true		String		Path of the EnergyPlus Weather (EPW) file.

Distribution Assumption(s)

No assumptions are made.

Public Use Microdata Area

Description

The Public Use Microdata Area (PUMA) from 2010 U.S. Census that the sample is located. PUMAs are a collection of census tracts that do not cross state boundaries. They contain no fewer than 100,000 people and typically represent no more than 200,000 people. PUMAs are smaller in land area when located near large cities compared to rural areas. PUMAs typically do not follow County boundaries. A map of the 2010 PUMAs can be seen in Figure 5.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.

Figure 5. 2010 Public Use Microdata Area boundaries

Direct Conditional Dependencies

- County and PUMA.

Options

The options for PUMAs are structured by their state abbreviation and the PUMA code from the GISJOIN code. The GISJOIN values are found in the 2010 TIGER/LINE Basis file on the IPUMS GIS Boundary Files website. An example is G01002100, which represents state FIPS code AL, and 02100 is the AL, Elmore, Autauga, Montgomery -Outer- and Lowndes Counties PUMA.

There are three ResStock arguments set with the PUMA options: `site_elevation`, `site_latitude`, and `site_longitude`. All three of these arguments are set to "auto" and use the default OpenStudio-HPXML Building Site values.

Table 5. The ResStock argument definitions set in the PUMA characteristic

Name	Required	Units	Type	Choices	Description
`site_elevation`	false	ft	Double	auto	Elevation of the home address.
`site_latitude`	false	deg	Double	auto	Latitude of the home address. Must be between -90 and 90. Use negative values for southern hemisphere.
`site_longitude`	false	deg	Double	auto	Longitude of the home address. Must be between -180 and 180. Use negative values for the western hemisphere.

Distribution Assumption(s)

No assumptions are made.

County and PUMA

Description

The GISJOIN identifier for the County and the PUMA where the sample is located. Since Counties and PUMAs are both a collection of census tracts, often a PUMA is in multiple counties. This characteristic describes the combination of County and PUMA where the sample is located.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004.

Options

The options for County and PUMA are a combination of the NHGIS GISJOIN Code for the County and the PUMA separated by a comma. An example option is "G0100010, G01002100"—G0100010 is the County GISJOIN for Autauga County, AL, and G01002100 is the PUMA GISJOIN for the AL, Elmore, Autauga, Montgomery -Outer- and Lowndes Counties PUMA.

Distribution Assumption(s)

No assumptions are made.

Metropolitan and Micropolitan Statistical Area

Description

The U.S. Metropolitan Statistical Area (MSA) or Micropolitan Statistical Area (MicroSA) where sample is located. The U.S. Census defines a set of counties as Core-Based Statistical Areas (CBSAs). These CBSAs are either assigned a MicroSA or combined into a larger MSA. According to the U.S. Census, each metropolitan statistical area must have at least one urban area of 50,000 or more inhabitants. According to the U.S. Census, each MicroSA must have at least one urban area of at least 10,000 but less than 50,000 population.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- County-MSA crosswalk comes from the Quarterly Census of Employment and Wages NAICS-based data between 2013 and 2022 by the U.S. Bureau of Labor Statistics (https://www.bls.gov/cew/classifications/areas/county-msa-csa-crosswalk.htm).

Direct Conditional Dependencies

- County.

Options

Options of the Metropolitan and Micropolitan Statistical Area characteristic are structured by having the name of the MSA or MicroSA, a comma, the State abbreviation, and either “MSA” or “MicroSA.” An example is “Albany-Schenectady-Troy, NY MSA,” which corresponds to the Albany-Schenectady-Troy MSA in New York State.

Distribution Assumption(s)

No assumptions are made.

City

Description

The City where the sample is located.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Cities are defined by Census blocks by their Census Place in the 2010 Census.
- Unit counts are from the American Community Survey 5-year 2016.

Direct Conditional Dependencies

- County and PUMA.

Options

The options are structured as the State abbreviation of the city, a comma, and the name of the city. An example is “AR, Jonesboro,” which corresponds to Jonesboro, Arkansas.

The ResStock argument `site_city` is assigned in the City characteristic. The argument is set to “auto,” which is the OpenStudio-HPXML default value; see the OpenStudio-HPXML Building Site section of the documentation for the default values.

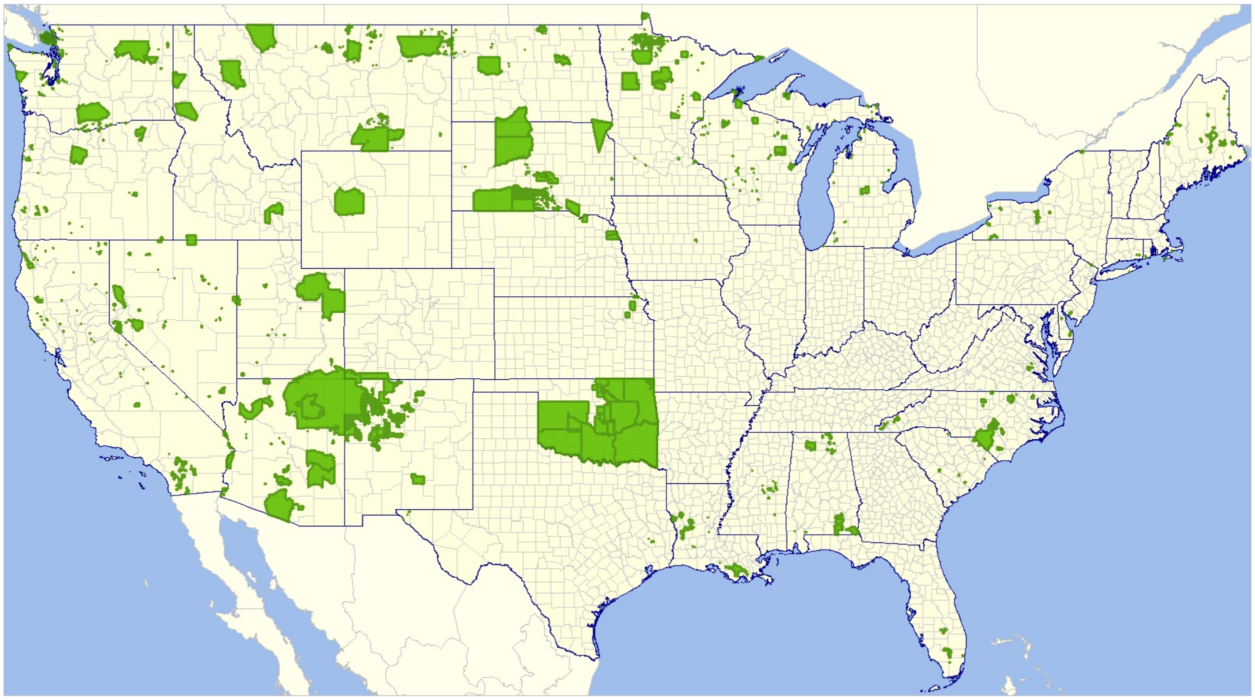


Figure 6. AIANNH area map. The image is created by ProximityOne and excludes Alaska and Hawaii.

Table 6. The ResStock argument definitions set in the City characteristic

Name	Required	Type	Description
`site_city`	false	String	City/municipality of the home address.

Distribution Assumption(s)

- 2020 Decennial Redistricting data were used to map tract-level unit counts to census blocks.
- 1,099 cities are tagged in ResStock, but there are over 29,000 Places in the Census data.
- The threshold for including a Census Place in the City characteristic is 15,000 housing units.
- The value "In Another Census Place" designates the fraction of housing units in a Census Place with fewer total housing units than the threshold.
- The value "Not in a Census Place" designates the fraction of housing units not in a Census Place according to the 2010 Census.

AIANNH Area

Description

American Indian/Alaska Native/Native Hawaiian (AIANNH) Area where the sample is located. See Figure 6 for a map of AIANNH areas in the contiguous United States.

Distribution Data Source(s)

- 2010 Census Tract to American Indian Area (AIA) Relationship File provides the percent housing units in the census tract that belong to AIA.
- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.

Direct Conditional Dependencies

- County and PUMA.

Options

The options are either “Yes” or “No,” indicating if the housing unit is in an AIANNH area.

Distribution Assumption(s)

- The 2010 Census Tracts are mapped to 2015 County and PUMA by adjusting for known geographic changes (e.g., renaming of Shannon County to Oglala Lakota County, SD) However, Tract=G3600530940103 (Oneida city, Madison County, NY) could not be mapped to County and PUMA and was removed. The tract contains only 11 units for AIA.

County Metro Status

Description

The Metro Status of the county where the sample is located and is based on MSA and MicroSA.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- County-MSA crosswalk comes from the Quarterly Census of Employment and Wages NAICS-based data between 2013 and 2022 by the U.S. Bureau of Labor Statistics.

Direct Conditional Dependencies

- Metropolitan and Micropolitan Statistical Area.

Options

The options are either “Metropolitan” or “Non-Metropolitan.”

Distribution Assumption(s)

No assumptions are made.

PUMA Metro Status

Description

The PUMA metropolitan status where the housing unit is located.

Distribution Data Source(s)

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- PUMA.

Options

The options are either (1) In metro area, not/partially in principal city, (2) In metro area, principal city, or (3) Not/-partially in metro area.

Distribution Assumption(s)

- The PUMA Metro Status, derived from ACS IPUMS METRO codes, indicates whether the household resided within a metropolitan area and, for households in metropolitan areas, whether the household resided within or outside of a central/principal city. Each PUMA has a unique METRO status in ACS and therefore has a unique PUMA Metro Status. IPUMS derives METRO codes for samples not directly identified based on available geographic information and whether the associated county group or PUMA lies wholly or only partially within metropolitan areas or principal cities.

8.1.2 Climate Zones

This section of ResStock characteristics is a set of climate zone definitions. There are five input files to ResStock that specify climate zones:

- ASHRAE IECC Climate Zone 2004
- ASHRAE IECC Climate Zone 2004—Sub-CZ Split
- Building America Climate Zones
- California Energy Commission (CEC) Climate Zones
- ENERGY STAR® Climate Zone 2023.

ASHRAE IECC Climate Zone 2004

Description

Climate zone according to ASHRAE 169 in 2004 and IECC in 2012 where the sample is located. See Figure 7 for a map of the climate zones.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- Climate zone data are from ASHRAE 169 2004, IECC 2012, and M.C. Baechler 2015.

Direct Conditional Dependencies

There are no direct conditional dependencies.

Options

A set of counties defines each climate and moisture zone. Climate zones range from 1–8 and moisture zones are indicated by A, B, and C.

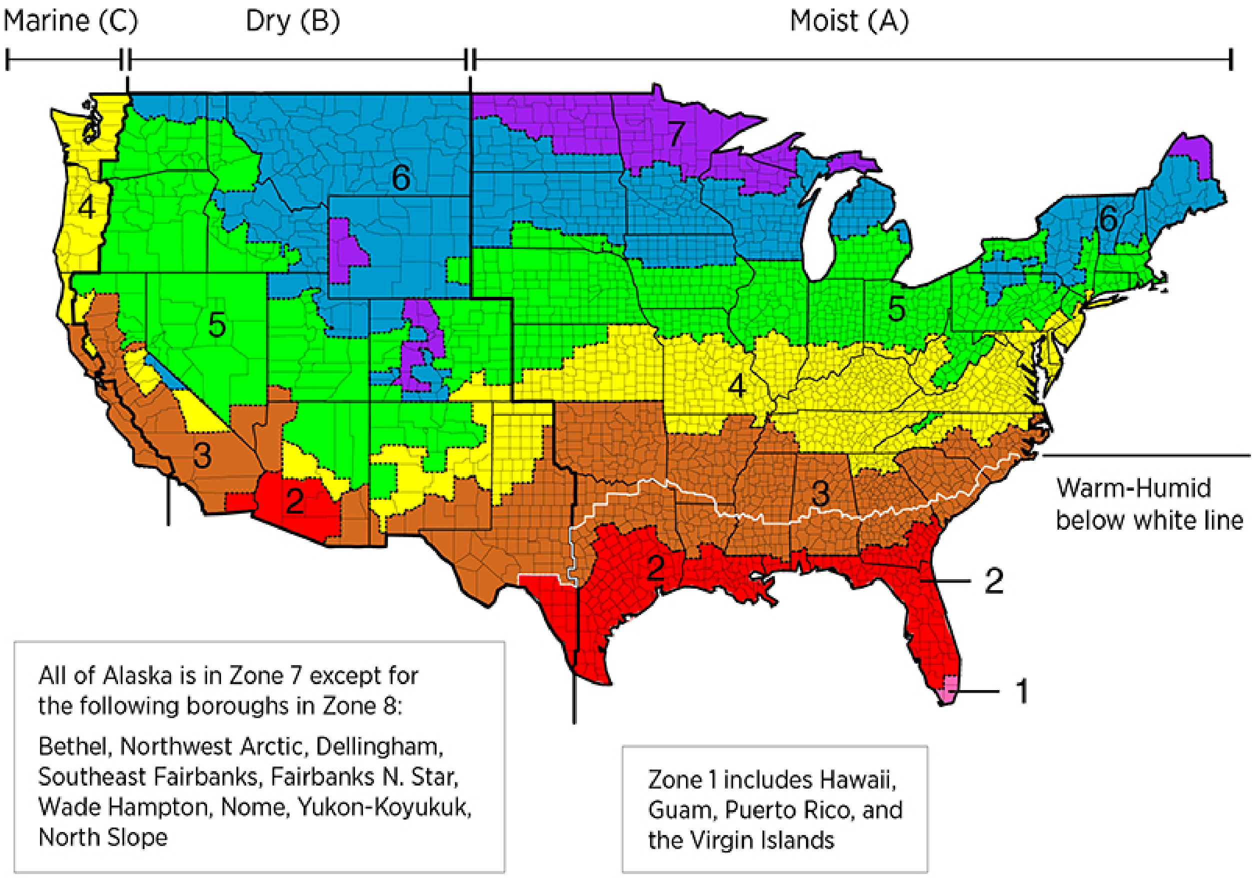
The ASHRAE IECC Climate Zone 2004 sets the `site_type` and `site_iecc_zone` arguments. The `site_type` is always set to "auto." The `site_iecc_zone` argument matches the climate zone with the exception of climate zones 7 and 8 in Alaska. ResStock departs from the climate zone definitions by using 7AK and 8AK instead of 7 and 8 from the standards.

Table 7. The ResStock arguments set in the ASHRAE IECC Climate Zone 2004 characteristic

Name	Required	Type	Choices	Description
`site_type`	false	Choice	auto, suburban, urban, rural	The type of site.
`site_iecc_zone`	false	Choice	auto, 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, 3C, 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, 6C, 7, 8	IECC zone of the home address.

Distribution Assumption(s)

No assumptions are made.



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:

Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Figure 7. The 2004 ASHRAE 169 and IECC 2012 climate zone map

ASHRAE IECC Climate Zone 2004 – Sub-CZ Split

Description

The climate zone, according to ASHRAE 169 in 2004 and IECC in 2012, where the sample is located. Climate zone where climate zone 2A is split between counties in (1) TX and LA, and (2) FL, GA, AL, and MS. Climate zone where climate zone 1A is split between counties in (1) HI, and (2) FL. See Figure 7 for the climate zones and the climate zone 2A counties that are split between the states mentioned previously.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- Climate zone data are from ASHRAE 169 2004, IECC 2012, and M.C. Baechler 2015.

Direct Conditional Dependencies

- County.

Options

A set of counties defines each climate and moisture zone. Climate zones range from 1–8 and moisture zones are indicated by A, B, and C. Climate zone 2A is split between options “2A—FL, GA, AL, MS” and “2A—TX, LA.”

Distribution Assumption(s)

- This characteristic is used to better represent HVAC types in the 2A climate zone.
- This characteristic is used to better represent partial conditioning in the 1A climate zone.

Building America Climate Zones

Description

The Building America Climate Zone where the sample is located. See Figure 8 for a map of the climate zones.[1]

Distribution Data Source(s)

- Unit counts are from the American Community Survey 5-year 2016.
- Spatial definitions are from U.S. Census 2010.
- Climate zone data are from ASHRAE 169 2004, IECC 2012, and M.C. Baechler 2015.

Direct Conditional Dependencies

- County.

Options

The options for the Building America Climate Zone characteristic are the same as the climate zones: Cold, Hot-Dry, Hot-Humid, Marine, Mixed-Dry, Mixed-Humid, Subarctic, and Very Cold.

Distribution Assumption(s)

No assumptions are made.

California Energy Commission Climate Zones

Description

The CEC Climate Zone where the sample is located. See Figure 9 for a map of the CEC building climate zones.

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[1] The Subarctic climate zone is not shown and is only found in Alaska.

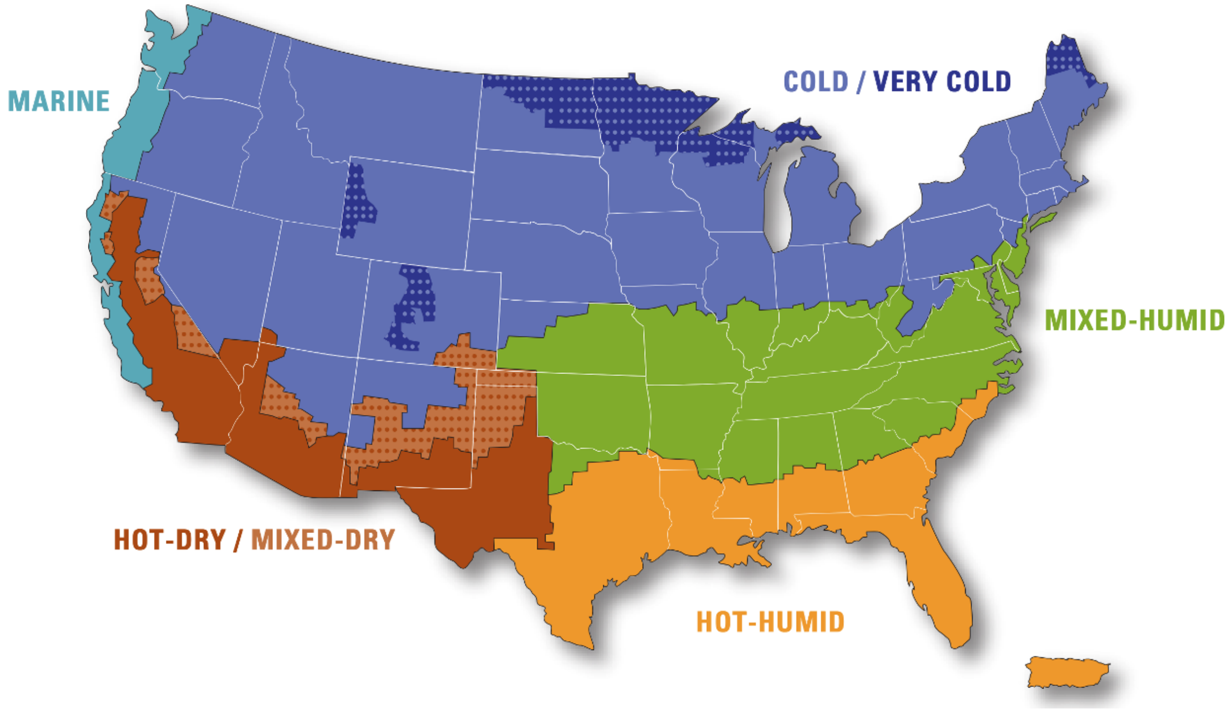


Figure 8. Building America Climate Zone map

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Zip code definitions are from the end of Q2 2020.
- The climate zone to zip codes in California are from the CEC website.

Direct Conditional Dependencies

- County and PUMA.

Options

The options range from 1–16 in California. For other states, the option is set to None.

Distribution Assumption(s)

- CEC Climate zones are defined by zip codes.
- The dependency selected is County and PUMA as zip codes are not modeled in ResStock.
- The mapping between Census Tracts and zip codes is approximate and some discrepancies may exist.

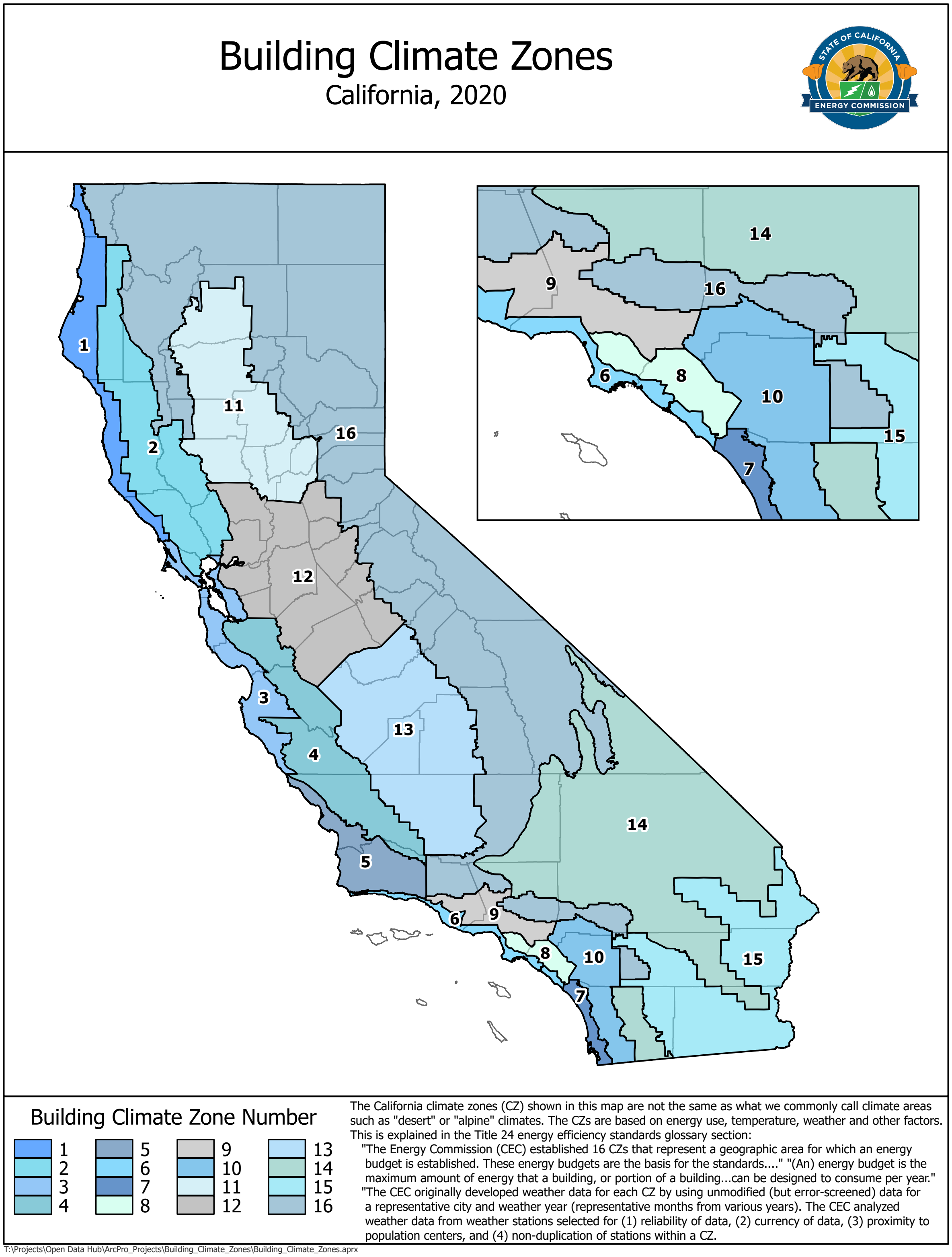
ENERGY STAR Climate Zone 2023

Description

Climate zones for windows, doors, and skylights per ENERGY STAR guidelines as of 2023. See Figure 10 for a map of the climate zones.

Distribution Data Source(s)

- Area definition approximated based on published map retrieved in May 2023 from the ENERGY STAR windows, doors, and skylights key product criteria website.



The California climate zones (CZ) shown in this map are not the same as what we commonly call climate areas such as "desert" or "alpine" climates. The CZs are based on energy use, temperature, weather and other factors. This is explained in the Title 24 energy efficiency standards glossary section:

"The Energy Commission (CEC) established 16 CZs that represent a geographic area for which an energy budget is established. These energy budgets are the basis for the standards...." "(An) energy budget is the maximum amount of energy that a building, or portion of a building...can be designed to consume per year."

"The CEC originally developed weather data for each CZ by using unmodified (but error-screened) data for a representative city and weather year (representative months from various years). The CEC analyzed weather data from weather stations selected for (1) reliability of data, (2) currency of data, (3) proximity to population centers, and (4) non-duplication of stations within a CZ.

Figure 9. California Energy Commission Building Climate Zone map

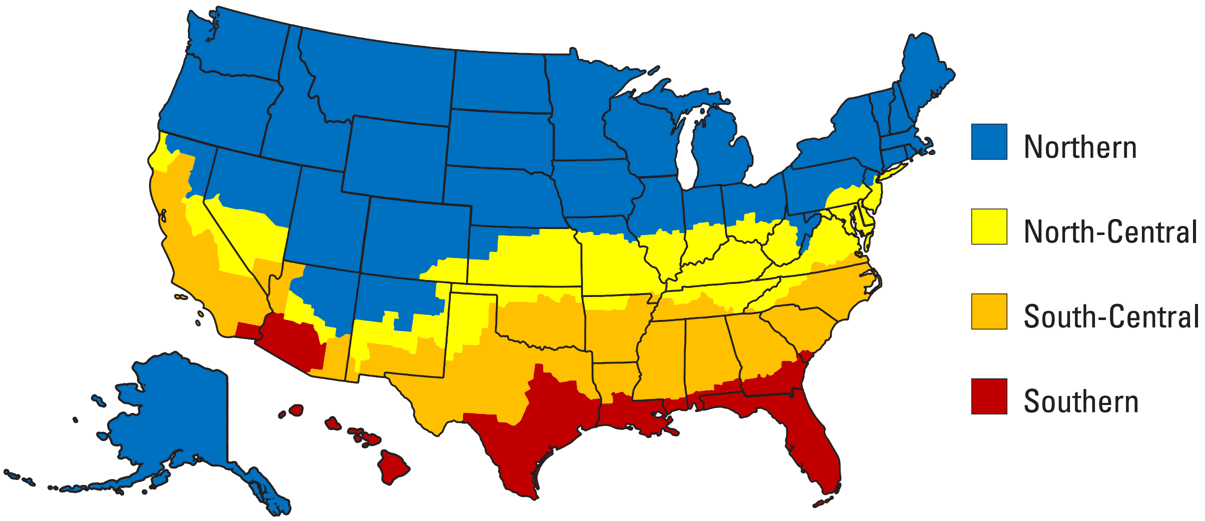


Figure 10. ENERGY STAR V7 climate zone map

Direct Conditional Dependencies

- CEC Climate Zone
- County.

Options

The options for the ENERGY STAR Climate Zone 2023 characteristic are the same as climate zones: North-Central, Northern, South-Central, and Southern.

Distribution Assumption(s)

- ENERGY STAR Climate Zones assigned based on CEC Climate Zone for California and based on County everywhere else.

8.1.3 Grid and Emissions Geographies

In ResStock there are three input files describing geographies relevant to the electric grid and emissions calculations:

- ReEDS Balancing Area
- Generation and Emissions Assessment (GEA) Region
- ISO RTO Region.

ReEDS Balancing Area

Description

The Regional Energy Deployment System Model (ReEDS) balancing area where the sample is located. See Figure 11 to see a map of the balancing areas.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- Regional Energy Deployment System (ReEDS) Model Documentation: Version 2019 (Brown et al. 2020)

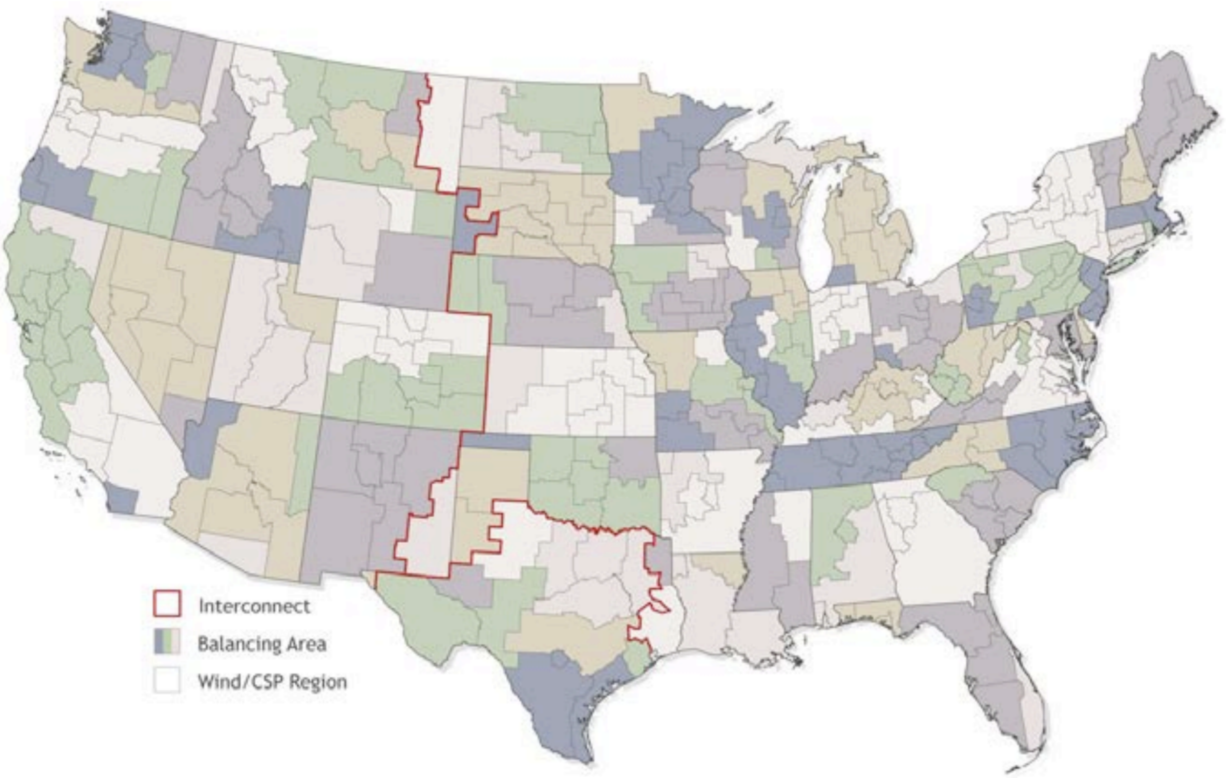


Figure 11. ReEDS balancing area map

Direct Conditional Dependencies

- County.

Options

The options for the ReEDS Balancing Area characteristic is a set of integers 1-134 based on Figure 11. Alaska and Hawaii do not have a ReEDS balancing area and are labeled with the None option.

Distribution Assumption(s)

No assumptions are made.

Generation and Emissions Assessment (GEA) Region

Description

The 2023 and later Cambium generation and carbon emissions assessment region where the sample is located. See Figure 12 for a map of these regions.

Distribution Data Source(s)

- Cambium Documentation: Version 2024 (Gagnon et al. 2025).

Direct Conditional Dependencies

- County.

Options

The options follow the Cambium GEA region names: CAISO, ERCOT, FRCC, ISONE, MISO Central, MISO North, MISO South, None, Northern Grid East, Northern Grid South, Northern Grid West, NYISO, PJM East, PJM West,

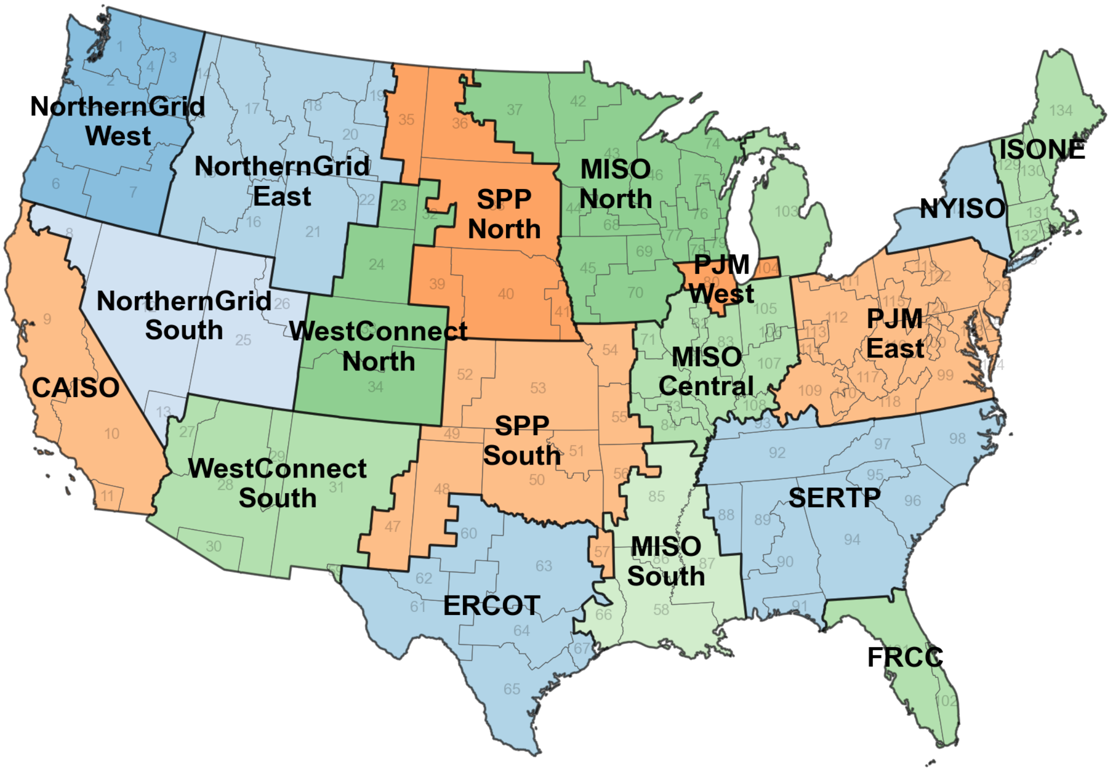


Figure 12. Map of the Cambium 2023 Generation and Emission Assessment Regions

SERTP, SPP North, SPP South, West Connect North, and West Connect South. The None option is set for Alaska and Hawaii as these states are not modeled in Cambium.

Distribution Assumption(s)
No assumptions are made.

ISO RTO Region

Description
The independent system operator (ISO) or regional transmission organization (RTO) region where the sample is located.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- ISO and RTO regions are from EIA Form 861, 2018.

Direct Conditional Dependencies

- County

Options
The options are a list of options that represent ISOs and RTOs:

- Pennsylvania New Jersey Maryland Interconnection (PJM)
- Midcontinent Independent System Operator (MISO)
- Electric Reliability Council of Texas (ERCOT)
- California ISO (CAISO)
- New York ISO (NYISO)
- Southwest Power Pool (SPP)
- ISO New England (NEISO).

If the county is not in any of these regions, the option is listed as the None option.

Distribution Assumption(s)
No assumptions were made.

8.1.4 Other Geographies

In this section, we cover other miscellaneous geographies in ResStock. This includes four input files:

- Census Division RECS
- Custom State
- Location Region
- American Housing Survey Region.

Census Division RECS

Description
Census Division as used in RECS 2015 where the sample is located.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- U.S. EIA 2015 RECS codebook.

Direct Conditional Dependencies

- State.

Options
The options match the names of the Census divisions except for RECS 2015 splits the Mountain Census Division into North (CO, ID, MT, UT, WY) and South (AZ, NM, NV).

Distribution Assumption(s)
No assumptions were made.

Custom State

Description
A custom selection of states to be able to have more fine-tuned probability distribution in states where we have more data.

Distribution Data Source(s)
No data sources were used.

Direct Conditional Dependencies

- State.

Options
The options for the Custom State characteristic are “AK” and “Others.” The characteristic was added during the calibration of Alaska to integrate the Alaska Retrofit Information System data.

Distribution Assumption(s)
No assumptions were made.

Location Region

Description
A custom ResStock region constructed of EIA RECS 2009 reportable domains where the sample is located. See Figure 13 for a map of these regions.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- U.S. EIA 2009 RECS microdata.

Direct Conditional Dependencies

- State.

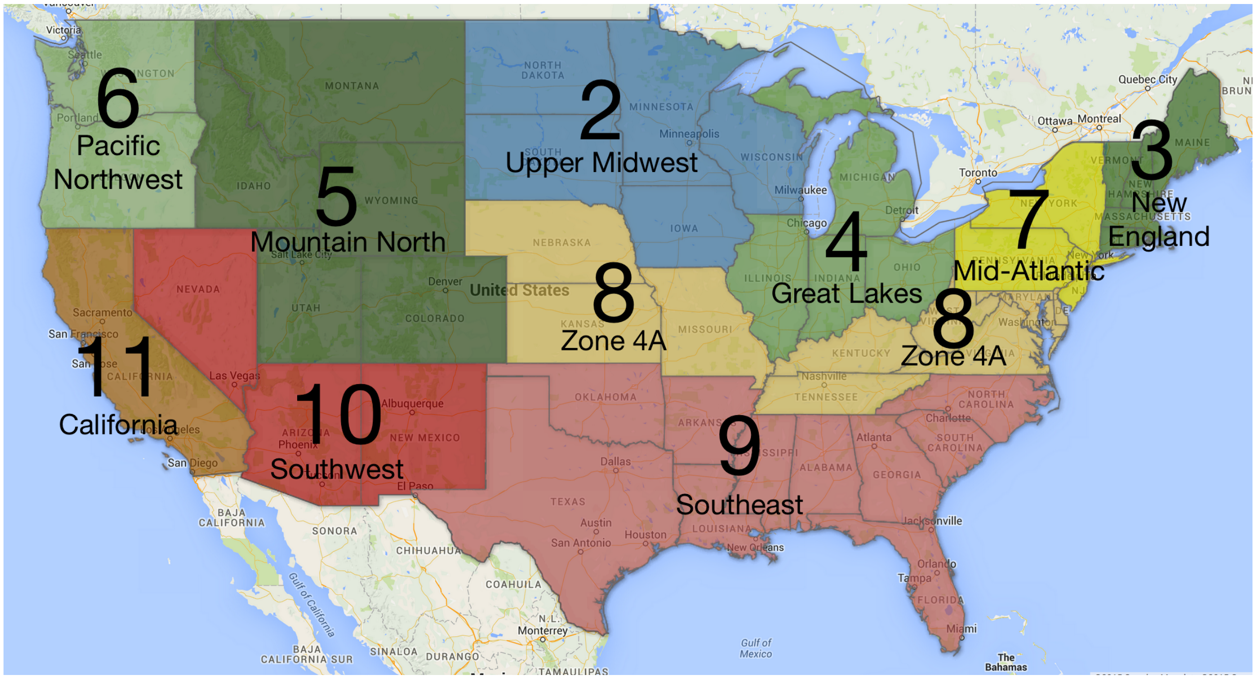


Figure 13. Map of the custom regions in ResStock. Alaska and Hawaii are their own custom regions.

Options

A list of custom regions (CRs) that range from CR02–CR11. These numbered CRs are the historical options of the contiguous United States. When Alaska and Hawaii were added, CRAK and CRHI options were added, respectively.

Distribution Assumption(s)

No assumptions are made.

American Housing Survey Region

Description

The American Housing Survey region where the sample is located.

Distribution Data Source(s)

- Spatial definitions are from the U.S. Census Bureau as of July 1, 2015.
- Unit counts are from the American Community Survey 5-year 2016.
- Core Based Statistical Area (CBSA) data based on the Feb 2013 CBSA delineation file.
- 2013 American Housing Survey microdata.

Direct Conditional Dependencies

- County.

Options

Using the American Housing Survey microdata, 15 of the largest core-based statistical areas (CBSAs) were separated from their census divisions. This process resulted in 15 CBSA geographies and 9 Census Division Geographies that do not include the list of largest CBSAs. The list of options are: CBSA Atlanta-Sandy Springs-Roswell, GA; CBSA Boston-Cambridge-Newton, MA-NH; CBSA Chicago-Naperville-Elgin, IL-IN-WI; CBSA Dallas-Fort Worth-Arlington, TX; CBSA Detroit-Warren-Dearborn, MI; CBSA Houston-The Woodlands-Sugar Land, TX; CBSA Los Angeles-Long Beach-Anaheim, CA; CBSA Miami-Fort Lauderdale-West Palm Beach, FL; CBSA New

York-Newark-Jersey City, NY-NJ-PA; CBSA Philadelphia-Camden-Wilmington, PA-NJ-DE-MD; CBSA Phoenix-Mesa-Scottsdale, AZ; CBSA Riverside-San Bernardino-Ontario, CA; CBSA San Francisco-Oakland-Hayward, CA; CBSA Seattle-Tacoma-Bellevue, WA CBSA Washington-Arlington-Alexandria, DC-VA-MD-WV; Non-CBSA East North Central; Non-CBSA East South Central; Non-CBSA Middle Atlantic; Non-CBSA Mountain; Non-CBSA New England; Non-CBSA Pacific; Non-CBSA South Atlantic; Non-CBSA West North Central; and Non-CBSA West South Central.

Distribution Assumption(s)

No assumptions were made.

8.1.5 Weather Data

Weather data are closely related to the specification of geography inputs, since weather varies by location. In ResStock, weather data are not specified in the Housing Characteristics input data like most things, but are specified as their own set of input files. In ResStock, weather files are specified at the county level, although sometimes adjacent counties share the same weather files.

As is standard in most building energy models, ResStock can be run with either Typical Meteorological Year (TMY) or Actual Meteorological Year (AMY) data. Hypothetically, ResStock could be run with any other weather data in EPW format, but all data releases to date have been based upon TMY or AMY data. TMY are synthetically constructed files based upon historic weather where each month of the year is picked from the most representative (i.e., "typical") real month from the previous 30 years (Wilcox and Marion 2008). This has the advantage of avoiding extreme or unusual weather, and can be appropriate for analyses that aggregate annual energy use. However, TMY files, by design, will not capture worst-case or extreme situations. Also, given that TMYs are constructed upon historical weather, it is unlikely they truly represent what is "typical" for a location given the reality of accelerating climate change. "Typical" is a moving target, and what was typical 10 years ago is less likely to be typical today. Furthermore, TMY has the disadvantage that adjacent weather stations might not use the same historical years for the same months. For example, a TMY in Denver, CO, might use 2012 for the July file, but 30 miles (40 kilometers) away, the Boulder, CO, TMY station might use 1999 for July. This misalignment of weather years can lead to modeling of non-coincident temporal energy use in ResStock and will likely lead to the underrepresentation of electricity peaks when considering geographies spread across more than one weather file.

AMY weather files overcome the location misalignment issue by using real weather data from a recent historical year. Having a recent file also helps with some of the historical bias from constructing files from data up to 30 years old, but it does not capture future climate change-driven weather patterns. A potential problem with AMY is that it inherits any abnormalities that occurred in a given year. For example, if a particular year was unusually cold, cooling demands would be lower than you might generally see and heating loads a bit higher. In ResStock, we generally run our models with both 2018 AMY and TMY weather (Bianchi and Fontanini 2021). 2018 is a year for which we have sufficient metered data for comparison, and it is also a compatible year for many grid simulation tools.

Weather File Development

Since ResStock is a composite model of many EnergyPlus models, it employs the standard EnergyPlus Weather (EPW) files (Big Ladder Software 2015). The EPW weather format provides a timeseries dataset of a wide array of weather variables across all 8,760 hours of a non-leap year. These weather variables provide the climatic inputs for simulating heat transfer at each time step for each model within ResStock. For the TMY files, we use the most recent release, TMY3 from Wilcox and Marion (2008).[2] For AMY, we construct our own EPW files for internal use that are not available to the public. Some of the weather variables needed to construct an EPW are available on the Load Profiles OEDI submission.

We develop custom AMY weather data files by pulling historic hourly temperature, humidity, wind speed/direction, and atmospheric pressure from the Integrated Surface Database, developed by the National Oceanic and Atmospheric Administration's National Climatic Data Center. Additionally, we add in satellite-derived solar radiation data from NREL's National Solar Radiation Database (Sengupta et al. 2018). Ground-based solar radiation data are not widely collected, so using satellite-derived solar radiation data is standard practice for both the solar industry and building

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[2] In review of the TMY3 data, we have identified some outliers in the initially published TMY3 data (e.g., erroneous temperature spikes). We have corrected those for ResStock use and published our corrected versions (Bianchi and Fontanini 2021).

energy modelers using historical weather data. Caveats and further information on the data compilation and gap filling of this custom AMY approach can be found in Section 2.4 of Wilson et al. (2022).

Mapping Weather Files to ResStock Samples

To produce weather files for ResStock, we develop AMY EPWs for approximately 1,200 weather stations pulling data from the year 2018—with the 2018 AMY roughly mapping to the locations of the TMY3 data.[3] In ResStock, each county is assigned one of these available 1,200 weather stations. Each county will receive a weather station that is located in the county if one is available; if not, the county will be assigned a weather station closest to the county's population centroid, with prioritization of stations in the same climate zone. Timestamps are shifted if the chosen weather file is in a different time zone. All housing units within a given county will use the assigned weather data for that county for simulations. Within the model, actual weather file assignment occurs in the options_lookup.tsv as a parameter input into the ResStockArguments script.

Weather Files and Equipment Sizing

In addition to the 8,760 timeseries of weather variables in the timeseries energy simulation, EPW files also provide a header with basic information on the weather location. ResStock uses some of this header information for sizing HVAC equipment—see Table 8.

Table 8. Relevant fields from the EPW header

Field	Layer	Application
LOCATION	OS-HPXML	OpenStudio-HPXML uses the stated latitude, longitude, and elevation in the EPW header. At the moment, this does not control much in the simulation, but could be important for controlling solar water heating (not currently in ResStock).
DESIGN CONDITIONS	OS-HPXML	The design conditions of the EPW header are used in sizing HVAC equipment according to ACCA Manual J and system selection according to ACCA Manual S.
GROUND TEMPERATURES	N/A	Unused by ResStock. Instead OS-HPXML uses an analytical method to convert weather station temperatures to ground temperatures (Xing 2014).
HOLIDAYS/DAYLIGHT SAVINGS	ResStock	ResStock does not run daylight savings, so the "No" is passed through ResStock to OS-HPXML.

8.2 Geometry

In this section, we discuss the inputs that control the actual geometry of the building energy model used for simulation of each sample. We discuss the geometry parameters in five categories: housing unit location, building type, construction year, housing unit geometry, and space geometry.

8.2.1 Housing Unit Location

There are two reference frames for locating the housing units modeled in ResStock: (1) the building frame of reference and (2) the polar reference frame. The building frame defines the front, back, top, bottom, left, and right sides of the unit. The polar reference frame defines the orientation of the unit's front door with respect to the cardinal directions north, south, east, and west.

In ResStock, housing units are modeled as single zones, regardless if they are in larger buildings. To do this, adiabatic walls are assigned/modeled for walls, ceilings, or floors shared between the modeled housing unit, an adjacent unit, and a corridor.

The units are shaded by how near other buildings are to the modeled unit. OpenStudio-HPXML can model shading with exterior corridors for multifamily units, but ResStock does not use these capabilities for multifamily or single-family attached units.

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[3] Occasionally nearby stations are used if data are missing from the target weather station.

The height above grade for the unit is based on the the number of floors the average ceiling height and the unit level (top floor, middle floors, or bottom floor). The height above grade largely impacts the importance of wind driven infiltration. For bottom units the above grade height is 0 ft. For middle units, the average height of all middle units is used. For top units, the height of the top floor.

There are 12 input files controlling building siting in ResStock:

- Orientation
- Geometry Stories
- Geometry Stories Bin
- Geometry Building Type Height
- Geometry Stories Low Rise
- Geometry Building Number Units MF
- Geometry Building Number Units SFA
- Geometry Building Level MF
- Geometry Building Horizontal Location MF
- Geometry Building Horizontal Location SFA
- Neighbors
- Corridor.

Orientation

Description

Orientation of the front of the housing unit as it faces the street. The front door is assumed to face the street.

Distribution Data Source(s)

- OpenStreetMap data queried by Radiant Labs.

Direct Conditional Dependencies

No direct conditional dependencies.

Options

The options for the Orientation characteristic are east, west, northeast, southwest, north, south, northwest, and southeast. The options set the `geometry_unit_orientation` ResStock argument; see Table 9. The argument definition can be found in Table 10.

Table 9. Orientation options and arguments that vary for each option

Option name	Stock saturation	`geometry_unit_orientation`
East	17%	90
West	17%	270
Northeast	7.2%	45
Southwest	7.2%	225
North	18%	0
South	18%	180
Northwest	7.7%	315
Southeast	7.7%	135

For the argument definitions, see Table 12. See the OpenStudio-HPXML Building Construction documentation for the available HPXML schema elements, default values, and constraints.

Table 10. The ResStock argument definitions set in the Orientation characteristic

Name	Required	Units	Type	Description
`geometry_unit_orientation`	true	degrees	Double	The unit's orientation is measured clockwise from north (e.g., North=0, East=90, South=180, West=270).

Distribution Assumption(s)

No assumptions were made. The distribution was taken directly from the Radiant Labs query.

Geometry Stories

Description

The number of stories in the building in which the housing unit is located.

Distribution Data Source(s)

- U.S. EIA 2009 RECS microdata.

Direct Conditional Dependencies

- Geometry Building Type ACS
- Geometry Floor Area Bin.

Options

The options for Geometry stories are a set of integers between 1 and 35; see Table 11. The stories of a building refer to the number of floors above grade. The number of stories does not include basements but would include finished attics. The `geometry_num_floors_above_grade` argument definition is in Table 12.

Table 11. Geometry Stories options and arguments that vary for each option

Option name	Stock saturation	`geometry_num_floors_above_grade`
1	49%	1
2	37%	2
3	8%	3
4	2%	4
5	0.79%	5
6	0.7%	6
7	0.16%	7
8	0.16%	8
9	0.13%	9
10	0.17%	10
11	0.09%	11
12	0.19%	12
13	0.12%	13
14	0.11%	14

Table 11. Geometry Stories options and arguments that vary for each option

Option name	Stock saturation	`geometry_num_floors_above_grade`
15	0.12%	15
20	0.21%	20
21	0.66%	21
35	0.11%	35

For the argument definitions, see Table 12. See the OpenStudio-HPXML Building Construction documentation for the available HPXML schema elements, default values, and constraints.

Table 12. Argument definitions for the Geometry Stories characteristics

Name	Required	Units	Type	Description
`geometry_num_floors_above_grade`	true	#	Integer	The number of floors above grade (in the unit if single-family detached or single-family attached, and in the building if apartment unit). Conditioned attics are included.

Distribution Assumption(s)

- All mobile homes are 1 story.
- Single-Family Detached and Single-Family Attached use the STORIES field in RECS, whereas Multifamily with 5+ units uses the NUMFLRS field.
- Building types 2 Unit and 3 or 4 Unit use the stories distribution of Multifamily 5 to 9 Unit (capped at 4 stories) because RECS does not report stories or floors for multifamily with 2-4 units.
- The dependency on floor area bins is removed for multifamily with 5+ units.
- Vintage ACS rows for the 2010s are copied from the 2000-09 rows.

Geometry Story Bin

Description

Tags the building in which the housing unit is located as having more than 8 stories or less than 8 stories.

Distribution Data Source(s)

- U.S. EIA 2009 RECS microdata.

Direct Conditional Dependencies

- Geometry Stories.

Options

The options are either <8 stories or 8+ stories. This characteristic is an aggregation of the Geometry stories characteristic to identify units in high-rise buildings. No arguments are assigned based on this housing characteristic, but it is used as a dependency for other input files.

Table 13. Options and saturation for the Geometry Story Bin

Option name	Stock saturation
<8	98%
8+	2.1%

Distribution Assumption(s)

- The probability values are a direct mapping of the Geometry Stories characteristic.

Geometry Building Type Height

Description

The 2009 U.S. EIA RECS building type with multifamily buildings split out by low-rise, mid-rise, and high-rise.

Distribution Data Source(s)

- The assignment of building type and height are assigned based on the building type and the number of stories.

Direct Conditional Dependencies

- Geometry Building Type RECS
- Geometry Stories.

Options

The options break up the Geometry Building Type RECS multi-family 5+ unit buildings into low-rise (1–3 stories), mid-rise (4–7 stories), and high-rise (8+ stories). No arguments are directly assigned based on the options in this input file.

Table 14. Options and saturation for Geometry Building Type Height

Option name	Stock saturation
Mobile Home	6.2%
Multi-Family with 2-4 Units	8%
Multi-Family with 5+ Units, 1-3 Stories	13%
Multi-Family with 5+ Units, 4-7 Stories	3.4%
Multi-Family with 5+ Units, 8+ Stories	2.1%
Single-Family Attached	5.9%
Single-Family Detached	61%

Distribution Assumption(s)

No assumptions are made.

Geometry Stories Low Rise

Description

Number of building stories for low-rise buildings.

Distribution Data Source(s)

- The assignment of building type and height are assigned based on the number of stories.

Direct Conditional Dependencies

- Geometry Stories.

Options

The options are a categorization of the Geometry Stories characteristic for low-rise buildings (1 story, 2 stories, 3 stories, 4+ stories).

Distribution Assumption(s)

None.

Geometry Building Number Units MF

Description

The number of housing units in the multifamily building.

Distribution Data Source(s)

- U.S. EIA 2009 RECS microdata.

Direct Conditional Dependencies

- Geometry Building Type ACS
- Geometry Stories.

Options

The options for the Geometry Building Level MF characteristic are a set of integers between 2 and 326; see Table 15. The "None" option is used for all building types other than multifamily. The options set the `geometry_building_num_units` ResStock argument; see Table 16.

Table 15. Geometry Building Level Number of Units MF options and arguments that vary for each option

Option name	Stock saturation	`geometry_building_num_units`
2	3.6%	2
3	1.4%	3
4	3%	4
5	0.54%	5
6	1.5%	6
7	0.26%	7
8	2.3%	8
9	0.15%	9
10	0.95%	10
11	0.098%	11
12	1.9%	12
13	0.15%	13
14	0.18%	14
15	0.27%	15
16	0.61%	16
17	0.023%	17
18	0.22%	18
19	0.016%	19
20	0.75%	20
24	0.96%	24
30	0.81%	30
36	0.48%	36
43	0.67%	43
67	2.7%	67
116	1.2%	116

Table 15. Geometry Building Level Number of Units MF options and arguments that vary for each option

Option name	Stock saturation	`geometry_building_num_units`
183	0.62%	183
326	1%	326
None	74%	

For the argument definitions, see Table 16. See the OpenStudio-HPXML Whole-SFA-MF-Buildings documentation for the available HPXML schema elements, default values, and constraints.

Table 16. Argument definitions for the Geometry Building Number of Units MF characteristic

Name	Required	Units	Type	Description
`geometry_building_num_units`	false	#	Integer	The number of units in the building. Required for single-family attached and apartment units.

Distribution Assumption(s)

- Uses NUMAPTS (number of apartments) field in EIA RECS 2009
- EIA RECS 2009 does not report NUMAPTS for Multifamily 2–4 units, so assumptions are made based on the number of stories
- Data were sampled from the following bins of Geometry Stories: 1, 2, 3, 4-7, 8+.

Geometry Building Number Units Single-Family Attached

Description

The number of housing units in the single-family attached (SFA) building.

Distribution Data Source(s)

- U.S. EIA 2009 RECS microdata.

Direct Conditional Dependencies

- Geometry Building Type ACS.

Options

The options for the Geometry Building Level SFA characteristic are a set of integers between 2 and 144; see Table 17. The “None” option is used for all building types other than SFA.

Table 17. Geometry Building Level Number of Units SFA options and arguments that vary for each option

Option name	Stock saturation	`geometry_building_num_units`
None	94%	
2	0%	2
3	0%	3
4	0%	4
5	0.72%	5
6	0.78%	6
7	0.36%	7
8	1.1%	8

Table 17. Geometry Building Level Number of Units SFA options and arguments that vary for each option (continued)

Option name	Stock saturation	`geometry_building_num_units`
9	0%	9
10	0.38%	10
12	0.57%	12
15	0.14%	15
16	0.33%	16
20	0.27%	20
24	0.27%	24
30	0.27%	30
36	0.27%	36
50	0.13%	50
60	0.1%	60
90	0.086%	90
144	0.11%	144

For the argument definitions, see Table 16. See the OpenStudio-HPXML Whole-SFA-MF-Buildings documentation for the available HPXML schema elements, default values, and constraints.

Distribution Assumption(s)

No assumptions were made.

Geometry Building Level Multifamily

Description

Location of the multifamily (MF) unit vertically within the building (bottom, middle, top).

Distribution Data Source(s)

- Calculated directly from the Geometry Building Type RECS and Geometry Stories characteristics.

Direct Conditional Dependencies

- Geometry Building Type RECS
- Geometry Stories.

Options

The options for the Geometry Building Level MF characteristic are Bottom, Middle, None, and Top; see Table 18. The None option is used for all building types other than MF. The characteristic sets the `geometry_unit_level` ResStock argument; see Table 19.

Table 18. Geometry Building Level MF options and arguments that vary for each option

Option name	Stock saturation	`geometry_unit_level`
Bottom	11%	Bottom
Middle	6.1%	Middle
Top	8.9%	Top
None	74%	

For the argument definitions, see Table 19. See the OpenStudio-HPXML Building Construction documentation for the available HPXML schema elements, default values, and constraints.

Table 19. Argument definitions for the Geometry Building Level MF characteristic

Name	Required	Type	Choices	Description
`geometry_unit_level`	false	Choice	Bottom, Middle, Top	The level of the unit. This is required for apartment units.

Distribution Assumption(s)

- Calculated using the number of stories, where buildings greater than or equal to 2 stories have Top and Bottom probabilities = 1/Geometry Stories, and Middle probabilities = 1–2/Geometry stories.

Geometry Building Horizontal Location Multifamily

Description

Location of the multifamily unit horizontally within the building (left, middle, right).

Distribution Data Source(s)

- Calculated directly from the Geometry Number of Units MF and Geometry Stories characteristics.

Direct Conditional Dependencies

- Geometry Number of Units MF
- Geometry Stories.

Options

The options of the Geometry Building Horizontal Location MF characteristic are None, Left, Middle, Right, and Not Applicable. The characteristic sets the `geometry_unit_horizontal_location` ResStock argument; see Table 20. The “Not Applicable” option is used for a pair of number of units and stories that cannot be sampled. For example, a 9-story, 2-unit multifamily building is unlikely to exist in reality and cannot be modeled in ResStock. ResStock does not model units in buildings with more stories than units. All building types other than multifamily receive the “None” option. For the argument definitions, see Table 21.

Table 20. Geometry Building Horizontal Location Multifamily options and arguments that vary for each option

Option name	Stock saturation	`geometry_unit_horizontal_location`
Left	7.1%	Left
Middle	8%	Middle
Right	7.1%	Right
Not Applicable	4.2%	None
None	74%	

For the argument definitions, see Table 21. See the OpenStudio-HPXML Building Construction documentation for the available HPXML schema elements, default values, and constraints.

Table 21. Argument definitions for the Geometry Building Horizontal Location MF and Geometry Building Horizontal Location SFA characteristics

Name	Required	Type	Choices	Description
`geometry_unit_horizontal_location`	false	Choice	None, Left, Middle, Right	The horizontal location of the unit when viewing the front of the building. This is required for single-family attached and apartment units.

Distribution Assumption(s)

- All probabilities are calculated assuming the building has double-loaded corridors (with some exceptions like 3 units in a single-story building).

Geometry Building Horizontal Location Single-Family Attached

Description

Location of the SFA unit horizontally within the building (left, middle, right).

Distribution Data Source(s)

- Calculated directly from the Geometry Number of Units SFA and Geometry Stories characteristics.

Direct Conditional Dependencies

- Geometry Number of Units SFA
- Geometry Stories.

Options

The options of the Geometry Building Horizontal Location SFA characteristic are None, Left, Middle, and Right. The characteristic sets the `geometry_unit_horizontal_location` ResStock argument; see Table 22. All non-single-family-attached building types receive the “None” option. For the argument definitions, see Table 21.

Table 22. Geometry Building Horizontal Location SFA options and arguments that vary for each option

Option name	Stock saturation	`geometry_unit_horizontal_location`
Left	0.63%	Left
Middle	4.6%	Middle
Right	0.63%	Right
None	94%	

For the argument definitions, see Table 21. See the OpenStudio-HPXML Building Construction documentation for the available HPXML schema elements, default values, and constraints.

Distribution Assumption(s)

- All probabilities are calculated from the direct conditional dependencies.

Neighbors

Description

Presence and distance between the housing unit and the nearest neighbors to the left and right.

Distribution Data Source(s)

- OpenStreetMap data queried by Radiant Labs for Multifamily and Single-Family Attached
- Engineering judgment for others.

Direct Conditional Dependencies

- Geometry Building Type RECS.

Options

The options for Neighbors are Left/Right at 15 ft, 2, 4, 7, 12, 27, and None. The option values correspond to distances in feet to the nearest neighbor on the left and right sides of the building. The options set ResStock arguments corresponding to the distance and height a shading object. The `neighbor_front_height`, `neighbor_back_height`, `neighbor_left_height` and `neighbor_right_height` arguments are all set to “auto,” which sets the shading object height to the total height of the housing unit. The other arguments assign the distance from the housing unit. The `neighbor_front_distance` and `neighbor_back_distance` arguments are set to 0 (meaning there are no neighbors to the front and back of the unit). The left and right distances are set by Table 23. The None option sets distances to 0 (meaning there are no neighbors). The argument definitions can be seen in Table 24.

Table 23. Neighbors options and arguments that vary for each option

Option name	Stock saturation	`neighbor_left_distance`	`neighbor_right_distance`
Left/Right at 15ft	68%	15	15
2	0.19%	2	2
4	3.4%	4	4
7	5%	7	7
12	9.2%	12	12
27	13%	27	27
None	1.3%	0	0

For the argument definitions, see Table 24. See the OpenStudio-HPXML documentation section Neighbor Buildings for the available elements, default values, and constraints.

Table 24. The ResStock argument definitions set in the Neighbors characteristic

Name	Required	Units	Type	Choices	Description
`neighbor_front_distance`	true	ft	Double		The distance between the unit and the neighboring building to the front (not including eaves). A value of zero indicates no neighbors. Used for shading.
`neighbor_back_distance`	true	ft	Double		The distance between the unit and the neighboring building to the back (not including eaves). A value of zero indicates no neighbors. Used for shading.
`neighbor_left_distance`	true	ft	Double		The distance between the unit and the neighboring building to the left (not including eaves). A value of zero indicates no neighbors. Used for shading.
`neighbor_right_distance`	true	ft	Double		The distance between the unit and the neighboring building to the right (not including eaves). A value of zero indicates no neighbors. Used for shading.

Table 24. The ResStock argument definitions set in the Neighbors characteristic (continued)

Name	Required	Units	Type	Choices	Description
`neighbor_front_height`	false	ft	Double	auto	The height of the neighboring building to the front.
`neighbor_back_height`	false	ft	Double	auto	The height of the neighboring building to the back.
`neighbor_left_height`	false	ft	Double	auto	The height of the neighboring building to the left.
`neighbor_right_height`	false	ft	Double	auto	The height of the neighboring building to the right.

Distribution Assumption(s)

None

Corridor

Description

Type of corridor attached to multifamily units.

Modeling Approach

Single-family attached and multifamily buildings can have corridors, which are passageways between units. Interior corridors are enclosed and assumed to be conditioned, which are modeled by adiabatic walls being created for the wall of the unit that is adjacent to the corridor. Exterior corridors provide shading, but are not enclosed. The way this is modeled is to add a shading object to the front and/or the back of the unit. ResStock only allows multifamily units to have a double-loaded interior corridor. ResStock does not model energy use (e.g., lighting, plug load, or HVAC) associated with corridors; it only models their impact on the multifamily housing units.

Distribution Data Source(s)

- Engineering judgment.

Direct Conditional Dependencies

- Geometry Building Type RECS.

Options

For Mobile Homes, Single-Family Detached, and Single-Family Attached building types the option assigned is “Not Applicable.” Multifamily units all have a “Double-Loaded Interior” corridor with a width of 10 feet. The Corridor characteristic assigns the `geometry_corridor_position` and the `geometry_corridor_width` arguments. For the options and arguments set for each option, see Table 25. For the argument definitions, see Table 26.

Table 25. Corridor options and arguments that vary for each option

Option name	Stock saturation	`geometry_corridor_position`	`geometry_corridor_width`
Not Applicable	74%	None	0
Double-Loaded Interior	26%	Double-Loaded Interior	10
None	0%	None	0
Single Exterior Front	0%	Single Exterior (Front)	10

Double Exterior	0%	Double Exterior	10

For the argument definitions, see Table 26. See the OpenStudio-HPXML Dwelling Units documentation for the available HPXML schema elements, default values, and constraints.

Table 26. Argument definitions for the Corridor characteristic

Name	Required	Units	Type	Choices	Description
`geometry_corridor_position`	true		Choice	Double-Loaded Interior, Double Exterior, Single Exterior (Front), None	The position of the corridor. Only applies to single-family attached and apartment units. Exterior corridors are shaded, but not enclosed. Interior corridors are enclosed and conditioned.
`geometry_corridor_width`	true	ft	Double		The width of the corridor. Only applies to apartment units.

Distribution Assumption(s)

- Single-Family Attached units do not have corridors.
- All Multifamily units have a double-loaded interior corridor with a width of 10 ft.

8.2.2 Building Type

This section discusses the ResStock input files that control tagging and model differentiation of building type. These building types control a lot of assumptions and treatment of variables in the OpenStudio-HPXML workflow. An example is that the plug load energy is based on a regression equation, and the equation coefficients are different between the building types.

There are two input files controlling building type assignment in ResStock:

- Geometry Building Type ACS
- Geometry Building Type RECS.

Geometry Building Type ACS

Description

The building type classification according to the U.S. Census American Community Survey.

Distribution Data Source(s)

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- PUMA.

Options

ACS considers nine building types, which are tagged in ResStock based on PUMA. No arguments are directly assigned based on this input characteristic.

Table 27. Options and saturation for Geometry Building Type ACS

Option name	Stock saturation
2 Unit	3.6%
3 or 4 Unit	4.4%
5 to 9 Unit	4.7%
10 to 19 Unit	4.5%
20 to 49 Unit	3.7%
50 or More Unit	5.6%
Mobile Home	6.2%
Single-Family Attached	5.9%
Single-Family Detached	61%

Distribution Assumption(s)

None.

Geometry Building Type RECS

Description

The building type classification according to the U.S. EIA RECS.

Distribution Data Source(s)

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Geometry Building Type ACS.

Options

The EIA RECS building types are direct aggregations of the ACS building types. Multifamily units are grouped into 2–4 unit buildings and 5+ unit buildings. The options set the `geometry_unit_type`, `geometry_unit_aspect_ratio`, and `geometry_average_ceiling_height` ResStock arguments; see Table 28. The `geometry_average_ceiling_height` is always set to 8 ft. The argument definitions are in Table 29.

Table 28. Geometry Building Type RECS options and arguments that vary for each option

Option name	Stock saturation	`geometry_unit_type`	`geometry_unit_aspect_ratio`
Mobile Home	6.2%	manufactured home	1.8
Multifamily with 2–4 Units	8%	apartment unit	0.5556
Multifamily with 5+ Units	18%	apartment unit	0.5556
Single-Family Attached	5.9%	single-family attached	0.5556
Single-Family Detached	61%	single-family detached	1.8

For the argument definitions, see Table 29. See the OpenStudio-HPXML Building Construction documentation for the available HPXML schema elements, default values, and constraints.

Table 29. The ResStock argument definitions set in the Geometry Building Type RECS characteristic

Name	Required	Units	Type	Choices	Description
`geometry_unit_type`	true		Choice	single-family detached, single-family attached, apartment unit, manufactured home	The type of housing unit. Use single-family attached for a housing unit with 1 or more stories, attached units to one or both sides, and no units above/below. Use apartment unit for a housing unit with 1 story, attached units to one, two, or three sides, and units above and/or below.
`geometry_unit_aspect_ratio`	true	Frac	Double		The ratio of front/back wall length to left-/right wall length for the unit, excluding any protruding garage wall area.
`geometry_average_ceiling_height`	true	ft	Double		Average distance from the floor to the ceiling.

Distribution Assumption(s)

None.

8.2.3 Construction Year

ResStock captures the change in energy codes over time by relying on survey data (mainly from ACS and EIA RECS) to inform how housing units have adopted energy code vintages and retrofits over time. The approach used in ResStock is to assign a decadal bin when the building was constructed. The decadal bins range from pre-1940s to the 2010s. The Vintage and Vintage ACS characteristics are then used as dependencies to assign probabilities for each Vintage bin. For example, wall insulation being dependent on vintage allows the wall insulation R-value mean to increase over time.

There are two input files controlling building type assignment in ResStock:

- Vintage
- Vintage ACS.

Vintage

Description

Time period in which the building was originally constructed.

Distribution Data Source(s)

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Geometry Building Type ACS
- PUMA.

Options

The options are decade bins for when the building was constructed: <1940, 1940s, 1950s, 1960s, 1970s, 1980s, 1990s, 2000s, 2010s. The options set the `year_built` and `vintage` ResStock arguments. The `year_built` argument is always set to "auto." The `vintage` argument is set to the same value as the option name; see Table 30.

Table 30. Vintage options and arguments that vary for each option

Option name	Stock saturation	`vintage`
<1940	13%	<1940
1940s	4.9%	1940s
1950s	10%	1950s
1960s	11%	1960s
1970s	15%	1970s
1980s	13%	1980s
1990s	14%	1990s
2000s	14%	2000s
2010s	5.1%	2010s

For the argument definitions, see Table 31.

Table 31. The ResStock argument definitions set in the Vintage characteristic

Name	Required	Type	Description
`year_built`	false	Integer	The year the building was built.
`vintage`	false	String	The building vintage, used for informational purposes only.

Distribution Assumption(s)

- Where sample counts are less than 10 (812 / 21024 rows), the State average distribution has been inserted.
- "Mobile Home" does not exist in the PUMS DC sample and is replaced by "Single-Family Detached."

Vintage ACS

Description

Time period in which the housing unit was constructed as defined by the U.S. Census American Community Survey.

Distribution Data Source(s)

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Vintage.

Options

The options for Vintage ACS are the same vintage bins as ACS, 32. They are roughly 20-year bins. No arguments are set based on this input file.

Table 32. Option and saturation for Vintage ACS

Option name	Stock saturation
<1940	13%
1940–59	15%

Table 32. Option and saturation for Vintage ACS (continued)

Option name	Stock saturation
1960–79	26%
1980–99	27%
2000–09	14%
2010s	5.1%

Distribution Assumption(s)

- The Vintage ACS options are directly mapped from the Vintage characteristic options.

8.2.4 Housing Unit Geometry

There are seven input files controlling housing unit geometry in ResStock:

- Geometry Building Floor Area
- Geometry Building Floor Area Bin
- Bedrooms
- Geometry Attic Type
- Geometry Foundation Type
- Geometry Garage
- Geometry Space Combination.

Geometry Floor Area

Description

The conditioned floor area of the housing unit using bins from 2017–2019 American Housing Survey.

Distribution Data Source(s)

- 2017 and 2019 American Housing Survey microdata.

Direct Conditional Dependencies

- Census Division
- Geometry Building Type RECS
- Income RECS2020
- PUMA Metro Status
- Tenure.

Options

The options of Geometry Floor Area characteristic are the American Housing Survey floor area bins. The options set the `geometry_unit_cfa`, `geometry_unit_cfa_bin`, and the `geometry_garage_protrusion` ResStock arguments; see Table 33. The `geometry_unit_cfa` argument is always set to “auto.” Because in the ResStockArguments measure “auto” is used for the `geometry_unit_cfa` argument, a representative conditioned floor area is assigned using the `geometry_unit_cfa_bin` argument. The values of the conditioned floor area bin are taken from the 2017 and 2019 American Housing Surveys and split out by housing type. The housing types are single-family detached, single-family attached, apartment, and manufactured homes. Currently, the same conditioned floor area values are used for single-family detached and manufactured homes. For the ResStock argument definition see Table 34. See the OpenStudio-HPXML Building Construction section of the documentation. The floor area is used many places in the OpenStudio-HPXML model workflow.

Table 33. Geometry Floor Area options and arguments that vary for each option

Option name	`geometry_garage_protrusion`	`geometry_unit_cfa_bin`
0–499	0.72	0-499
500–749	0.75	500-749
750–999	0.5	750-999
1000–1499	0.5	1000-1499
1500–1999	0.5	1500-1999
2000–2499	0.5	2000-2499
2500–2999	0.5	2500-2999
3000–3999	0.5	3000-3999
4000+	0.5	4000+

Table 34. The ResStock argument definitions set in the Geometry Floor Area characteristic

Name	Required	Units	Type	Choices	Description
`geometry_unit_cfa_bin`	true		String		E.g., '2000-2499'.
`geometry_unit_cfa`	true	ft^2	Double		E.g., '2000' or 'auto'.
`geometry_garage_protrusion`	true	Frac	Double		The fraction of the garage that is protruding from the conditioned space. Only applies to single-family detached units.

Distribution Assumption(s)

- Due to low sample count, the characteristic distributions are constructed by downscaling a core input file with 4 sub-input files of different dependencies.
- Sub-input file 1 has dependencies: 'Census Division', 'PUMA Metro Status', 'Geometry Building Type RECS', 'Income RECS2020'
- Sub-input file 2 has dependencies: 'Census Division', 'PUMA Metro Status', 'Geometry Building Type RECS', 'Tenure'
- Sub-input file 3 has dependencies: 'Census Division', 'PUMA Metro Status', 'Geometry Building Type RECS', 'Vintage ACS'
- Sub-input file 4 has dependencies: 'Census Division', 'PUMA Metro Status', 'Income RECS2020', 'Tenure'.
- For each sub-input file, rows with <10 samples are replaced with coarsening dependency Census Region, followed by the national distribution.

Geometry Floor Area Bin

Description

The finished floor area of the housing unit using bins.

Distribution Data Source(s)

- Directly assigned from the Geometry Floor Area characteristic.

Direct Conditional Dependencies

- Geometry Floor Area.

Options
The options of the Geometry Floor Area Bin characteristic are 0–1499, 1500–2499, 2500–3999, and 4000+. These floor area bins options are a coarser representation than the Geometry Floor Area characteristic. The Geometry Floor Area Bin Characteristic is often used as a dependency for other characteristics.

Distribution Assumption(s)

- The options are directly assigned from the Geometry Floor area characteristic.

8.2.5 Space Geometry

Bedrooms

Description
The number of bedrooms in the housing unit.

Distribution Data Source(s)

- 2017 and 2019 American Housing Survey microdata.
- Building type categorization based on U.S. EIA 2009 RECS.

Direct Conditional Dependencies

- Geometry Building Type RECS
- Geometry Floor Area.

Options
The Bedrooms characteristic set the `geometry_unit_num_bedrooms` and the `geometry_unit_num_bathrooms` ResStock arguments. The options for bedrooms are integers from 1 to 5; see Table 35. The `geometry_unit_num_bathrooms` argument is always set to “auto.” For the argument definitions, see Table 36. See the OpenStudio-HPXML Building Construction section of the documentation. The number of bedrooms is used many places in the OpenStudio-HPXML model workflow.

Table 35. Bedroom options and arguments that vary for each option

Option name	`geometry_unit_num_bedrooms`
1	1
2	2
3	3
4	4
5	5

Table 36. The ResStock argument definitions set in the Bedrooms characteristic

Name	Required	Units	Type	Choices	Description
`geometry_unit_num_bedrooms`	true	#	Integer		The number of bedrooms in the unit.
`geometry_unit_num_bathrooms`	false	#	Integer	auto	The number of bathrooms in the unit.

Distribution Assumption(s)

- More than 5 bedrooms are labeled as 5 bedrooms and 0 bedrooms are labeled as 1 bedroom.
- Limit 0–499 ft^2 housing units to only 1 or 2 bedrooms. The geometry measure has a limit of (ffa-120)/70 >= bedrooms.

Geometry Attic Type

Description

The housing unit attic type.

Distribution Data Source(s)

- U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Census Division RECS
- Geometry Building Type RECS
- Geometry Stories Low Rise
- Vintage ACS.

Options

The options for Geometry Attic Type are Finished Attic or Cathedral Ceilings, Unvented Attic, Vented Attic. The None option is used for multifamily and mobile homes. The options in the Geometry Attic Type characteristic set the `geometry_attic_type`, `geometry_roof_type`, and `geometry_roof_pitch` ResStock arguments; see Table 37. The `geometry_roof_type` is always set to “gable.” The `geometry_roof_pitch` is always set to 6:12. For ResStock argument definitions, see Table 38. See OpenStudio-HPXML Attics section of the documentation for elements, constraints, and default values.

Table 37. Geometry Attic Type options and arguments that vary for each option

Option name	`geometry_attic_type`
Finished Attic or Cathedral Ceilings	ConditionedAttic
None	FlatRoof
Unvented Attic	UnventedAttic
Vented Attic	VentedAttic

Table 38. The ResStock argument definitions set in the Geometry Attic characteristic

Name	Required	Units	Type	Choices	Description
`geometry_attic_type`	true		Choice	FlatRoof, VentedAttic, UnventedAttic, ConditionedAttic, BelowApartment	The attic type of the building. Attic type ConditionedAttic is not allowed for apartment units.
`geometry_roof_type`	true		Choice	gable, hip	The roof type of the building. Ignored if the building has a flat roof.
`geometry_roof_pitch`	true		Choice	1:12, 2:12, 3:12, 4:12, 5:12, 6:12, 7:12, 8:12, 9:12, 10:12, 11:12, 12:12	The roof pitch of the attic. Ignored if the building has a flat roof.

Distribution Assumption(s)

- Multifamily building types and Mobile Homes have Flat Roof (None) only.
- 1-story Single-Family building types cannot have Finished Attic/Cathedral Ceiling because that attic type is modeled as a new story, and 1-story does not have a second story.
- 4+story Single-family and mobile homes are an impossible combination. The None option is assigned but not sampled.

Geometry Foundation Type

Description

The type of foundation.

Distribution Data Source(s)

- The sample counts and sample weights are constructed using U.S. EIA 2009 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Building Type RECS
- Vintage ACS.

Options

The options of the Geometry Foundation type characteristic are Ambient, Heated Basement, Slab, Unheated Basement, Unvented Crawlspace, and Vented Crawlspace. The options set the `geometry_foundation_type`, `geometry_foundation_height`, `geometry_foundation_height_above_grade`, and `geometry_rim_joist_height` ResStock arguments; see Table 39. For ResStock argument definitions, see Table 40. Another name for Ambient foundations is pier and beam.

Table 39. Geometry Foundation Type options and arguments that vary for each option

Option name	`geometry_foundation_type`	`geometry_foundation_height`	`geometry_foundation_height_above_grade`	`geometry_rim_joist_height`
Ambient	Ambient	4	4	0
Heated Basement	ConditionedBasement	8	1	9.25
Slab	SlabOnGrade	0	0	0
Unheated Basement	UnconditionedBasement	8	1	9.25
Unvented Crawlspace	UnventedCrawlspace	4	1	9.25
Vented Crawlspace	VentedCrawlspace	4	1	9.25

Table 40. The ResStock argument definitions set in the Geometry Foundation Type characteristic

Name	Required	Units	Type	Choices	Description
`geometry_foundation_type`	true		Choice	SlabOnGrade, VentedCrawlspace, UnventedCrawlspace, ConditionedCrawlspace, UnconditionedBasement, ConditionedBasement, Ambient, AboveApartment, BellyAndWingWithSkirt, BellyAndWingNoSkirt	The foundation type of the building. Foundation types ConditionedBasement and ConditionedCrawlspace are not allowed for apartment units.
`geometry_foundation_height`	true	ft	Double		The height of the foundation (e.g., 3 ft for crawlspace, 8 ft for basement). Only applies to basements/crawlspaces and Ambient.
`geometry_foundation_height_above_grade`	true	ft	Double		The depth above grade of the foundation wall. Only applies to basements/crawlspaces and Ambient.
`geometry_rim_joist_height`	false	in	Double		The height of the rim joists. Only applies to basements/crawlspaces.

Distribution Assumption(s)

- All mobile homes have Ambient foundations.
- Multifamily buildings cannot have Ambient or Heated Basements foundations.
- Single-family attached buildings cannot have Ambient foundations.
- All foundation types are used across all housing types except for mobile homes, which have constrained options.
- Because we need to assume a foundation type for ground-floor MF units, we use the lumped SFD+SFA distributions for MF2–4 and MF5+ building foundations. (RECS data for households in MF2–4 unit buildings are not useful since we do not know which floor the unit is on. RECS does not include foundation responses for households in MF5+ unit buildings.)
- For SFD and SFA, if no foundation type is specified, then the sample has Ambient foundation.

Geometry Garage

Description

The presence and size of an attached garage.

Distribution Data Source(s)

- U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Census Division RECS
- Geometry Building Type RECS
- Geometry Floor Area Bin
- Geometry Foundation Type
- Geometry Stories Low Rise.

Options

The options for the Geometry Garage characteristic are 1 Car, 2 Car, 3 Car, and None. The options set the `geometry_garage_width`, `geometry_garage_depth`, and `geometry_garage_position` ResStock arguments; see Table 41. The `geometry_garage_depth` argument is always set to 24 ft. The `geometry_garage_position` argument is always set to "Right." ResStock argument definitions can be seen in Table 42.

Table 41. Bedroom options and arguments that vary for each option

Option name	`geometry_garage_width`
1 Car	12
2 Car	24
3 Car	36
None	0

Table 42. The ResStock argument definitions set in the Geometry Garage characteristic

Name	Required	Units	Type	Choices	Description
`geometry_garage_width`	true	ft	Double		The width of the garage. Enter zero for no garage. Only applies to single-family detached units.
`geometry_garage_depth`	true	ft	Double		The depth of the garage. Only applies to single-family detached units.
`geometry_garage_position`	true		Choice	Right, Left	The position of the garage. Only applies to single-family detached units.

Distribution Assumption(s)

Most of the assumptions below are not from the survey data, but are constraints of the geometry modeling in OpenStudio and are set to avoid errors.

- Only Single-Family Detached homes are assigned a probability for attached garage.
- No garage for ambient (i.e., pier & beam) foundation type.
- Due to modeling constraints restricting that garage cannot be larger or deeper than livable space: Single-family detached units that are 0–1499 square feet can only have a maximum of a 1-car garage.
- Single-family detached units that are 0–1499 square feet and 3+ stories cannot have a garage.
- The geometry stories distributions are all the same except for 0–1499 square feet and 3 stories.
- Single-family detached units that are 1500–2499 square feet cannot have a 3-car garage.
- Single-family detached units that are 2500–3999 square feet and a heated basement cannot have a 3-car garage.

- Due to low sample sizes, the following sets of dependencies are progressively lumped together.
  1. Crawl, basements, and slab are lumped.
  2. Story levels are lumped together.
  3. Census Division RECS is grouped into Census Region.
  4. Vintage ACS is grouped into: pre-1960, 1960-1999, and 2000+.

Geometry Space Combination

Description
Valid combinations of building type, building level mf, attic, foundation, and garage.

Distribution Data Source(s)

- U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Geometry Attic Type
- Geometry Building Level MF
- Geometry Building Type RECS
- Geometry Foundation Type
- Geometry Garage.

Options
The options are a direct mapping of Geometry Building Type, Geometry Building Level MF, Geometry Foundation Type, Geometry Attic Type, and Geometry Garage.

Distribution Assumption(s)
No assumptions are made. The options of the dependencies are directly mapped into options of this characteristic.

8.3 Envelope

The envelope components of ResStock inputs interface closely with the Geometry inputs, but focus more on the materials and thermal properties of the envelope. In this section, we discuss the various input files that control the modeled envelope in ResStock by envelope component.

8.3.1 Walls

There are three major input files to ResStock that control the wall properties:

- Geometry Wall Type
- Geometry Wall Exterior Finish
- Insulation Wall.

Collectively, they specify the material choices and R-value of the housing unit walls.

Geometry Wall Type

Description
The wall material used for thermal mass calculations of exterior walls.

Distribution Data Source(s)

- HIFLD Parcel data.

Direct Conditional Dependencies

- Geometry Building Type RECS
- Geometry Story Bin
- State
- Vintage ACS.

Option(s)

ResStock models four different wall types: Brick, Concrete, Steel Frame, and Wood Frame. This is the interior structure of the wall, not the exterior cladding. This input file does not have any ResStock arguments, but other input files that influence the thermal properties of the model are dependent on Geometry Wall Type.

Distribution Assumption(s)

- Rows where sample size < 10 are replaced with aggregated values down-scaled from dep='State' to dep='Census Division RECS'.

Geometry Wall Exterior Finish

Description

Wall siding material and color. This is the main input file that provides the thermal property arguments for the exterior cladding of a wall.

Distribution Data Source(s)

- HIFLD Parcel data.

Direct Conditional Dependencies

- Geometry Wall Type
- State
- Vintage ACS.

Option(s)

ResStock uses 11 options (see Table 43) for the exterior finish of the walls—correlated with the Geometry Wall Type via the input dependencies. A portion of the wall R-value is attributable to this exterior finish.

Table 43. Geometry Wall Exterior Finish options and arguments that vary for each option

Option name	`wall_siding_type`	`wall_color`	`exterior_finish_r`
Aluminum, Light	aluminum siding	light	0.6
Brick, Light	brick veneer	light	0.7
Brick, Medium/Dark	brick veneer	medium dark	0.7
Fiber-Cement, Light	fiber cement siding	light	0.2
None	none	medium	0
Shingle, Asbestos, Medium	asbestos siding	medium	0.6

Table 43. Geometry Wall Exterior Finish options and arguments that vary for each option

Option name	`wall_siding_type`	`wall_color`	`exterior_finish_r`
Shingle, Composition, Medium	composite shingle siding	medium	0.6
Stucco, Light	stucco	light	0.2
Stucco, Medium/Dark	stucco	medium dark	0.2
Vinyl, Light	vinyl siding	light	0.6
Wood, Medium/Dark	wood siding	medium dark	1.4

For the argument definitions, see Table 44. See the OpenStudio-HPXML Walls documentation for the available HPXML schema elements, default values, and constraints.

Table 44. The ResStock argument definitions for the Geometry Exterior Finish characteristic

Name	Required	Units	Type	Choices	Description
`wall_siding_type`	false		Choice	auto, aluminum siding, asbestos siding, brick veneer, composite shingle siding, fiber cement siding, masonite siding, none, stucco, synthetic stucco, vinyl siding, wood siding	The siding type of the walls. Also applies to rim joists.
`wall_color`	false		Choice	auto, dark, light, medium, medium dark, reflective	The color of the walls. Also applies to rim joists.
`exterior_finish_r`	true	h-ft^2-R/Btu	Double		R-value of the exterior finish.

Distribution Assumption(s)

- Rows where sample size < 10 are replaced with aggregated values down-scaled from dep='State' to dep='Census Division RECS'
- Brick wall types are assumed to not have an additional brick exterior finish
- Steel and wood frame walls must have an exterior finish.

Insulation Wall

Description

Wall construction type and insulation level. Provides the main R-value for the walls of the home. This is in addition to the R-values provided by the exterior wall cladding.

Distribution Data Source(s)

- *Single-Family Heating and Cooling Requirements: Assumptions, Methods, and Summary Results* (Ritschard, Hanford, and Sezgen 1992).
- *Data Collection-Data Characterization Summary* from the NorthernSTAR Building America Partnership (Nettleton and Edwards 2012), as described in Roberts et al., *Assessment of the U.S. Department of Energy's Home Energy Score Tool* (2012), and Merket et al., *Building America Field Data Repository* webinar (2014).

Direct Conditional Dependencies

- Location Region
- Geometry Wall Type
- Vintage.

Option(s)

ResStock models 15 different Insulation Wall levels; see Table 45. These are based upon the Geometry Wall Type defined, but provide a distribution of insulation levels for each of those options.

Table 45. Insulation Wall options and arguments that vary for each option

Option name	`wall_type`	`wall_assembly_r`
Wood Stud, Uninsulated	WoodStud	3.4
Wood Stud, R-7	WoodStud	8.7
Wood Stud, R-11	WoodStud	10.3
Wood Stud, R-15	WoodStud	12.1
Wood Stud, R-19	WoodStud	15.4
CMU, 6-in Hollow, Uninsulated	ConcreteMasonryUnit	4
CMU, 6-in Hollow, R-7	ConcreteMasonryUnit	9.4
CMU, 6-in Hollow, R-11	ConcreteMasonryUnit	12.4
CMU, 6-in Hollow, R-15	ConcreteMasonryUnit	15
CMU, 6-in Hollow, R-19	ConcreteMasonryUnit	17.4
Brick, 12-in, 3-wythe, Uninsulated	StructuralBrick	4.9
Brick, 12-in, 3-wythe, R-7	StructuralBrick	10.3
Brick, 12-in, 3-wythe, R-11	StructuralBrick	13.3
Brick, 12-in, 3-wythe, R-15	StructuralBrick	15.9
Brick, 12-in, 3-wythe, R-19	StructuralBrick	18.3

For the argument definitions, see Table 46. See the OpenStudio-HPXML Walls documentation for the available HPXML schema elements, default values, and constraints.

Table 46. The ResStock argument definitions set in the Insulation Wall characteristic

Name	Required	Units	Type	Choices	Description
`wall_type`	true		Choice	WoodStud, ConcreteMasonryUnit, DoubleWoodStud, InsulatedConcreteForms, LogWall, StructuralInsulatedPanel, SolidConcrete, SteelFrame, Stone, StrawBale, StructuralBrick	The type of walls.
`wall_assembly_r`	true	h-ft^2-R/Btu	Double		Assembly R-value of the walls.

Distribution Assumption(s)

- Updated per new wall type from Lightbox, all wall type-specific distributions follow that of Wood Frame (WoodStud).

8.3.2 Roof and Ceiling

There are three input files describing thermal properties of the roof and/or ceilings of housing units:

- Insulation Roof
- Insulation Ceiling
- Roof Material.

Additionally, there is an input for defining Radiant Barriers in homes with attics, but it is not currently used in ResStock.

A major assumption in ResStock is that multifamily buildings and mobile homes do not have attics (see Section 8.2.5), so their insulation is assigned in Insulation Ceiling, while for other building types it is assigned in the Insulation Roof housing characteristic.

Insulation Roof

Description

Finished roof insulation level. Insulation levels for unfinished attics covered separately.

Distribution Data Source(s)

- Derived from Home Innovation Research Labs 1982–2007 Data
- NEEA Residential Building Stock Assessment, 2012.

Direct Conditional Dependencies

- Geometry Attic Type.

Option(s)

Insulation roof options correspond to the amount of insulation at the roof deck and if the roof is finished; see Table 47. A finished roof is a cathedralized construction of the roof. An unfinished roof corresponds to the roof deck being open to the attic.

Table 47. Insulation Roof options and arguments that vary for each option

Option name	`roof_assembly_r`
Unfinished, Uninsulated	2.3
Finished, Uninsulated	3.7
Finished, R-7	10.2
Finished, R-13	14.3
Finished, R-19	21.2
Finished, R-30	29.7
Finished, R-38	36.5
Finished, R-49	47.0

For the argument definitions, see Table 48. See the OpenStudio-HPXML Roofs documentation for the available HPXML schema elements, default values, and constraints.

Table 48. The ResStock argument definitions set in the Insulation Roof characteristic

Name	Required	Units	Type	Choices	Description
`roof_assembly_r`	true	h-ft^2-R/Btu	Double		Assembly R-value of the roof

Distribution Assumption(s)

None

Radiant Barrier

Description

Presence of radiant barrier in the attic (not currently used in ResStock).

Distribution Data Source(s)

- Not applicable
- All homes are assumed to not have attic radiant barriers installed.

Direct Conditional Dependencies

- Geometry Building Type RECS.

Option(s)

Three options for radiant barriers are available in ResStock: "Yes," "No," and "None"; see Table 49. "No" is assigned to homes with attics but without radiant barriers, while "None" is assigned to homes without attics. No homes in ResStock currently have the "Yes" option assigned.

Table 49. Radiant Barrier options and arguments that vary for each option

Option name	`radiant_barrier_attic_location`	`radiant_barrier_grade`
None	none	1
Yes	attic roof only	1
No	none	1

For the argument definitions, see Table 50. See the OpenStudio-HPXML Roofs documentation for the available HPXML schema elements, default values, and constraints.

Table 50. The ResStock argument definitions set in the Radiant Barrier characteristic

Name	Required	Type	Choices	Description
`radiant_barrier_attic_location`	false	Choice	auto, none, attic roof only, attic roof and gable walls, attic floor	The location of the radiant barrier in the attic
`radiant_barrier_grade`	false	Choice	auto, 1, 2, 3	The grade of the radiant barrier in the attic

Distribution Assumption(s)

None

Roof Material

Description

Roof material and color.

Distribution Data Source(s)

- U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Census Division RECS
- Geometry Building Type RECS
- Vintage ACS.

Option(s)

Seven roof material options are used in the ResStock baseline; see Table 51. These correspond to options available within OpenStudio-HPXML and have thermal properties associated with each within OpenStudio-HPXML, but this is not specified at the ResStock level.

Table 51. Roof Material options and arguments that vary for each option

Option name	`roof_material_type`	`roof_color`
Asphalt Shingles, Medium	asphalt or fiberglass shingles	medium
Composition Shingles	asphalt or fiberglass shingles	medium
Metal, Dark	metal surfacing	dark
Slate	slate or tile shingles	medium
Tile, Clay or Ceramic	slate or tile shingles	medium
Tile, Concrete	slate or tile shingles	medium
Wood Shingles	wood shingles or shakes	medium

For the argument definitions, see Table 52. See the OpenStudio-HPXML Roof documentation for the available HPXML schema elements, default values, and constraints.

Table 52. The ResStock argument definitions set in the Roof Material characteristic

Name	Required	Type	Choices	Description
`roof_material_type`	false	Choice	auto, asphalt or fiberglass shingles, concrete, cool roof, slate or tile shingles, expanded polystyrene sheathing, metal surfacing, plastic/rubber/synthetic sheeting, shingles, wood shingles or shakes	The material type of the roof
`roof_color`	false	Choice	auto, dark, light, medium, medium dark, reflective	The color of the roof

Distribution Assumption(s)

- Multifamily with 5+ Units is assigned ‘Asphalt Shingles, Medium’ only.
- Due to low samples, Vintage ACS is progressively grouped into: pre-1960, 1960–1999, and 2000+.
- Geometry Building Type RECS is progressively grouped into: Single-Family (including Mobile Home), and Multifamily.
- Census Division RECS is coarsened to Census Region.

Insulation Ceiling

Description

This characteristic in ResStock specifies the insulation level of the ceiling on the top floor of the home in housing units with vented or unvented attics.

Distribution Data Source(s)

- NEEA Residential Building Stock Assessment, 2012.
- *Data Collection-Data Characterization Summary* from the NorthernSTAR Building America Partnership (Nettleton and Edwards 2012), as described in Roberts et al., *Assessment of the U.S. Department of Energy's Home Energy Score Tool* (2012) and Merket et al., *Building America Field Data Repository* webinar, 2014.
- Derived from Home Innovation Research Labs 1982-2007 Data.

Direct Conditional Dependencies

- Geometry Attic Type
- Location Region
- Vintage.

Option(s)

The options are levels of ceiling insulation by R-value; see Table 53. Uninsulated indicates that the housing unit could have ceiling insulation, but doesn't, whereas "None" indicates the housing unit cannot have ceiling insulation because it does not have an unfinished attic.

Table 53. Insulation Ceiling options and arguments that vary for each option

Option name	`ceiling_-assembly_r`	`ceiling_-insulation_r`
None	0	0
Uninsulated	2.1	0
R-7	8.7	7
R-13	14.6	13
R-19	20.6	19
R-30	31.6	30
R-38	39.6	38
R-49	50.6	49

For the argument definitions, see Table 54. See the OpenStudio-HPXML Attics documentation for the available HPXML schema elements, default values, and constraints.

Table 54. The ResStock argument definitions set in the Insulation Ceiling characteristic

Name	Required	Units	Type	Description
`ceiling_-assembly_r`	true	h-ft^2-R/Btu	Double	Assembly R-value for the ceiling (attic floor).
`ceiling_-insulation_r`	true	h-ft^2-R/Btu	Double	Nominal R-value for the ceiling (attic floor).

Distribution Assumption(s)

- Vented Attic has the same distribution as Unvented Attic
- CRHI is a copy of CR09

- CRAK is a copy of CR02.

8.3.3 Foundation

Five input files specify insulation and heat transfer parameters with the ground:

- Insulation Floor
- Insulation Foundation Wall
- Insulation Rim Joist
- Insulation Slab
- Ground Thermal Conductivity.

The inputs starting with "Insulation" specify insulation levels that vary depending upon Geometry Foundation Type (Section 8.2.5).

Insulation Floor

Description

Sets the insulation levels of all foundation types except for slab-on-grade.

Distribution Data Source(s)

- Derived from Home Innovation Research Labs 1982–2007 Data
- Pre-1980 uses engineering judgment.

Direct Conditional Dependencies

- Location Region
- Vintage
- Geometry Building Type RECS
- Geometry Foundation Type.

Option(s)

ResStock has three different levels of floor insulation, plus a None option that is assigned to buildings with an illegible foundation type for the Insulation Floor characteristic; see Table 55. All options set the `floor_type` to `WoodFrame`.

Table 55. Insulation Floor options and arguments that vary for each option

Option name	`floor_over_foundation_assembly_r`	`floor_over_garage_assembly_r`
None	0	5.3
Uninsulated	5.3	5.3
Ceiling R-13	17.8	17.8
Ceiling R-19	22.6	22.6
Ceiling R-30	30.3	30.3

For the argument definitions, see Table 56. See the OpenStudio-HPXML Floors documentation for the available HPXML schema elements, default values, and constraints.

Table 56. The ResStock argument definitions set in the Insulation Floor characteristic

Name	Required	Units	Type	Choices	Description
`floor_over_foundation_assembly_r`	true	h-ft^2-R/Btu	Double		Assembly R-value for the floor over the foundation. Ignored if the building has a slab-on-grade foundation.
`floor_over_garage_assembly_r`	true	h-ft^2-R/Btu	Double		Assembly R-value for the floor over the garage. Ignored unless the building has a garage under conditioned space.
`floor_type`	true		Choice	WoodFrame, StructuralInsulatedPanel, SolidConcrete, SteelFrame	The type of floors.

Distribution Assumption(s)

- CRHI is a copy of CR09
- CRAK is a copy of CR02.

Insulation Slab

Description

Defines the insulation level for all slab-on-grade foundation types.

Distribution Data Source(s)

- Derived from Home Innovation Research Labs 1982–2007 Data
- Pre-1980 uses engineering judgment.

Direct Conditional Dependencies

- Location Region
- Vintage
- Geometry Building Type RECS
- Geometry Foundation Type.

Option(s)

ResStock uses eight different options for Insulation Slab, plus a “None” flag for homes without a slab-on-grade foundation; see Table 57. The options specify both the R-value as well as the location of the slab insulation. The ResStock arguments `slab_thickness`,`slab_carpet_fraction`, and `slab_carpet_r` are constant across all the options and are all set to auto. The ResStock arguments `slab_under_insulation_width`, `slab_exterior_horizontal_insulation_width`, and `lab_exterior_horizontal_insulation_depth_below_grade` are constant and set to 0.

Table 57. Insulation Slab options and arguments that vary for each option

Option name	`slab_perimeter_insulation_r`	`slab_perimeter_depth`	`slab_under_insulation_r`	`slab_under_insulation_width`
None	0	0	0	0
Uninsulated	0	0	0	0
2ft R5 Under, Horizontal	0	0	5	2
2ft R10 Under, Horizontal	0	0	10	2
4ft R5 Under, Horizontal	0	0	5	4
2ft R5 Perimeter, Vertical	5	2	0	0
2ft R10 Perimeter, Vertical	10	2	0	0
R10 Whole Slab, Horizontal	0	0	10	999

For the argument definitions, see Table 58. See the OpenStudio-HPXML Slabs documentation for the available HPXML schema elements, default values, and constraints.

Table 58. The ResStock argument definitions set in the Insulation Slab characteristic

Name	Required	Units	Type	Choices	Description
`slab_perimeter_insulation_r`	true	h-ft^2-R/Btu	Double		Nominal R-value of the vertical slab perimeter insulation. Applies to slab-on-grade foundations and basement/crawlspace floors.
`slab_perimeter_insulation_depth`	true	ft	Double		Depth from grade to bottom of vertical slab perimeter insulation. Applies to slab-on-grade foundations and basement/crawlspace floors.
`slab_exterior_horizontal_insulation_width`	false	h-ft^2-R/Btu	Double		Nominal R-value of the slab exterior horizontal insulation. Applies to slab-on-grade foundations and basement/crawlspace floors.

Table 58. The ResStock argument definitions set in the Insulation Slab characteristic (continued)

Name	Required	Units	Type	Choices	Description
`slab_exterior_horizontal_insulation_width`	false	ft	Double		Width of the slab exterior horizontal insulation measured from the exterior surface of the vertical slab perimeter insulation. Applies to slab-on-grade foundations and basement/crawlspace floors.
`slab_exterior_horizontal_insulation_depth_below_grade`	false	ft	Double		Depth of the slab exterior horizontal insulation measured from the top surface of the slab exterior horizontal insulation. Applies to slab-on-grade foundations and basement/crawlspace floors.
`slab_under_insulation_r`	true	h-ft^2-R/Btu	Double		Nominal R-value of the horizontal under slab insulation. Applies to slab-on-grade foundations and basement/crawlspace floors.
`slab_under_insulation_width`	true	ft	Double		Width from slab edge inward of horizontal under-slab insulation. Enter 999 to specify that the under slab insulation spans the entire slab. Applies to slab-on-grade foundations and basement/crawlspace floors.
`slab_thickness`	false	in	Double	auto	The thickness of the slab. Zero can be entered if there is a dirt floor instead of a slab.
`slab_carpet_fraction`	false	Frac	Double	auto	Fraction of the slab floor area that is carpeted.
`slab_carpet_r`	false	h-ft^2-R/Btu	Double	auto	R-value of the slab carpet.

Distribution Assumption(s)

- CRHI is a copy of CR09
- CRAK is a copy of CR02.

Insulation Foundation Wall

Description

Specifies the insulation level of foundation types with foundation walls (i.e., crawlspaces and basements).

Distribution Data Source(s)

- Derived from Home Innovation Research Labs 1982–2007 Data
- Pre-1980 uses engineering judgment.

Direct Conditional Dependencies

- Location Region
- Vintage
- Geometry Building Type RECS
- Geometry Foundation Type.

Option(s)

ResStock provides four different options for Insulation Foundation Wall, plus a "None" flag for homes without foundation walls (Table 59). Several ResStock arguments are constant across all options: `foundation_wall_thickness` and `foundation_wall_assembly_r` are always set to *auto*, `foundation_wall_insulation_location` is always *exterior*, and `foundation_wall_insulation_distance_to_top` is 0.

Table 59. Insulation Foundation Wall options and arguments that vary for each option

Option name	`foundation_wall_type`	`foundation_wall_insulation_r`	`foundation_wall_insulation_distance_to_bottom`
None	solid concrete	0	0
Uninsulated	solid concrete	0	0
Wall R-5, Exterior	solid concrete	5	auto
Wall R-10, Exterior	solid concrete	10	auto
Wall R-15, Exterior	solid concrete	15	auto

For the argument definitions, see Table 60. See the OpenStudio-HPXML Foundation Walls documentation for the available HPXML schema elements, default values, and constraints.

Table 60. The ResStock argument definitions set in the Insulation Foundation Wall characteristic

Name	Required	Units	Type	Choices	Description
`foundation_wall_type`	false		Choice	auto, solid concrete, concrete block, concrete block foam core, concrete block perlite core, concrete block vermiculite core, concrete block solid core, double brick, wood	The material type of the foundation wall.
`foundation_wall_thickness`	false	in	Double	auto	The thickness of the foundation wall.

Table 60. The ResStock argument definitions set in the Insulation Foundation Wall characteristic (continued)

Name	Required	Units	Type	Choices	Description
`foundation_wall_insulation_r`	true	h-ft^2-R/Btu	Double		Nominal R-value for the foundation wall insulation. Only applies to basements/crawlspaces.
`foundation_wall_insulation_location`	false	ft	Choice	auto, interior, exterior	Whether the insulation is on the interior or exterior of the foundation wall. Only applies to basements/crawlspaces.
`foundation_wall_insulation_distance_to_top`	false	ft	Double	auto	The distance from the top of the foundation wall to the top of the foundation wall insulation. Only applies to basements/crawlspaces.
`foundation_wall_insulation_distance_to_bottom`	false	ft	Double	auto	The distance from the top of the foundation wall to the bottom of the foundation wall insulation. Only applies to basements/crawlspaces.
`foundation_wall_assembly_r`	false	h-ft^2-R/Btu	Double		Assembly R-value for the foundation walls. Only applies to basements/crawlspaces. If provided, overrides the previous foundation wall insulation inputs.

Distribution Assumption(s)

- CRHI is a copy of CR09
- CRAK is a copy of CR02.

Insulation Rim Joist

Description

Insulation level for rim joists. Set the same as the insulation level for the foundation wall.

Distribution Data Source(s)

- Engineering judgment.

Direct Conditional Dependencies

- Insulation Foundation Wall.

Option(s)

ResStock uses four different levels of rim-joist insulation as well as a “None” flag for homes without rim joists. These options map directly to the foundation wall insulation levels. The ResStock argument for `rim_joist_assembly_r` is always set to *auto*, and `rim_joist_continuous_interior_r` and `rim_joist_assembly_interior_r` are both set to 0 for all options.

Table 61. Options and saturation for Insulation Rim Joist

Option name	Stock saturation	`rim_joist_continuous_exterior_r`
None	48%	0
Uninsulated	47%	0
R-5, Exterior	1.2%	5
R-10, Exterior	2.8%	10
R-15, Exterior	0.52%	15

For the argument definitions, see Table 62. See the OpenStudio-HPXML Rim Joists documentation for the available HPXML schema elements, default values, and constraints.

Table 62. The ResStock argument definitions set in the Rim Joist characteristic

Name	Required	Units	Type	Choices	Description
`rim_joist_assembly_r`	false	h-ft^2-R/Btu	Double		Assembly R-value for the rim joists. Only applies to basements/crawlspaces. Required if a rim joist height is provided.
`rim_joist_continuous_exterior_r`	true	h-ft^2-R/Btu	Double		Nominal R-value for the rim joist continuous exterior insulation. Only applies to basements/crawlspaces.
`rim_joist_continuous_interior_r`	true	h-ft^2-R/Btu	Double		Nominal R-value for the rim joist continuous interior insulation that runs parallel to floor joists. Only applies to basements/crawlspaces.
`rim_joist_assembly_interior_r`	true	h-ft^2-R/Btu	Double		Assembly R-value for the rim joist assembly interior insulation that runs perpendicular to floor joists. Only applies to basements/crawlspaces.

Distribution Assumption(s)

- Rim joist insulation is the same value as the foundation wall insulation.

Ground Thermal Conductivity

Description

The thermal conductivity (in Btu/hr-ft-F) of the ground used in foundation and geothermal heat pump heat transfer calculations.

Distribution Data Source(s)

- Data from the Southern Methodist University Geothermal Laboratory. The data are from the Thermal Conductivity Observation in Content Model Format dataset. The data are available at https://www.smu.edu/dedman/academics/departments/earth-sciences/research/geothermallab/datamaps/ngds-project.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004.

Option(s)

ResStock uses 8 options for Thermal Ground Conductivity, which is expressed in BTU/hr-ft-F (Table 63). The ResStock arguments associated with each option vary only in the `site_ground_conductivity` parameter. The other two arguments, `site_soil_and_moisture_type` and `site_ground_diffusivity`, both receive `auto` assignment, regardless of the ResStock option.

Table 63. Ground Thermal Conductivity options and arguments that vary for each option

Option name	`site_ground_conductivity`
0.5	0.5
0.8	0.8
1.1	1.1
1.4	1.4
1.7	1.7
2.0	2.0
2.3	2.3
2.6	2.6

For the argument definitions, see Table 64. See the OpenStudio-HPXML Site documentation for the available HPXML schema elements, default values, and constraints.

Table 64. The ResStock argument definitions set in the Ground Thermal Conductivity characteristic

Name	Required	Units	Type	Choices	Description
`site_soil_and_moisture_type`	false		Choice	auto, clay, dry, clay, mixed, clay, wet, gravel, dry, gravel, mixed, gravel, wet, loam, dry, loam, mixed, loam, wet, sand, dry, sand, mixed, sand, wet, silt, dry, silt, mixed, silt, wet, unknown, dry, unknown, mixed, unknown, wet	Type of soil and moisture. This is used to inform ground conductivity and diffusivity.

Table 64. The ResStock argument definitions set in the Ground Thermal Conductivity characteristic

Name	Required	Units	Type	Choices	Description
`site_ground_conductivity`	false	Btu/hr-ft-F	Double		Conductivity of the ground soil. If provided, overrides the previous soil and moisture type input.
`site_ground_diffusivity`	false	ft^2/hr	Double		Diffusivity of the ground soil. If provided, overrides the previous soil and moisture type input.

Distribution Assumption(s)

- The data obtained are from surveyed oil and gas well data.
- The latitudes and longitudes were assigned to counties and the data were joined to the ResStock spatial lookup tables. In this process, 1,482 of 59,332 samples did not have a FIPS match or did not have data and were dropped.
- Due to limited data in climate zone 1A, data were pulled from samples in 1A plus Florida 2A.
- Samples less than 0.5 Btu/hr-ft-F are assigned a value of 0.5 Btu/hr-ft-F. Samples greater than 2.6 Btu/hr-ft-F are assigned a value of 2.6 Btu/hr-ft-F.

8.3.4 Doors and Windows

In ResStock, two input files control door specification in ResStock:

- Doors
- Door Area.

Two similar input files specify windows:

- Windows
- Window Areas.

Discussed also in this section are building features that might impact shading in windows. All three of these inputs are either not used or have constant values for the entire stock:

- Interior Shading
- Eaves
- Overhangs.

Door Area

Description

Area of exterior doors. All ResStock models currently receive the same option.

Distribution Data Source(s)

- Engineering judgment.

Direct Conditional Dependencies

- None.

Option(s)
All ResStock housing units currently receive an option of 20 ft^2 for the exterior area of doors; see Table 65.

Table 65. Door Area options and arguments that vary for each option

Option name	`door_area`
20 ft^2	20

For the argument definitions, see Table 66. See the OpenStudio-HPXML Doors documentation for the available HPXML schema elements, default values, and constraints.

Table 66. The ResStock argument definitions set in the Door Area characteristic

Name	Required	Units	Type	Description
`door_area`	true	ft^2	Double	The area of the opaque door(s).

Distribution Assumption(s)
None

Doors

Description
Exterior door material and properties.

Distribution Data Source(s)

- Engineering judgment.

Direct Conditional Dependencies

- None

Option(s)
All homes in ResStock receive Fiberglass doors with an R-value of 5 (Table 67).

Table 67. Door options and arguments that vary for each option

Option name	`door_rvalue`
Fiberglass	5

For the argument definitions, see Table 68. See the OpenStudio-HPXML Doors documentation for the available HPXML schema elements, default values, and constraints.

Table 68. The ResStock argument definitions set in the Door characteristic

Name	Required	Units	Type	Choices	Description
`door_rvalue`	true	h-ft^2-R/Btu	Double		R-value of the opaque door(s)

Distribution Assumption(s)
None.

Windows

Description

Construction type and efficiency levels of windows.

Distribution Data Source(s)

- U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Federal Poverty Level
- Geometry Building Type RECS
- Tenure
- Vintage ACS.

Option(s)

ResStock uses 10 window options in the baseline, with variation across number of panes, low-emissivity coating, and frame material. Across all Window options, multiple ResStock arguments are constant (Table 69). `window_natvent_availability`, `window_exterior_shading_winter`, `window_exterior_shading_summer`, `window_shading_summer_season`, and `skylight_storm_type` are all set to *auto*. Furthermore, two skylight window parameters are constant: `skylight_ufactor` is always set to 0.37 and `skylight_shgc` is always 0.3.

Table 69. Windows options and arguments that vary for each option

Option name	`window_ufactor`	`window_shgc`
Single, Clear, Metal	1.16	0.76
Single, Clear, Metal, Exterior Clear Storm	0.67	0.56
Single, Clear, Non-metal	0.84	0.63
Single, Clear, Non-metal, Exterior Clear Storm	0.47	0.54
Double, Clear, Metal, Air	0.76	0.67
Double, Clear, Metal, Air, Exterior Clear Storm	0.55	0.51
Double, Clear, Non-metal, Air	0.49	0.56
Double, Clear, Non-metal, Air, Exterior Clear Storm	0.34	0.49
Double, Low-E, Non-metal, Air, M-Gain	0.38	0.44
Triple, Low-E, Non-metal, Air, L-Gain	0.29	0.26

For the argument definitions, see Table 70. See the OpenStudio-HPXML Windows documentation for the available HPXML schema elements, default values, and constraints.

Table 70. The ResStock argument definitions set in the Windows characteristic

Name	Required	Units	Type	Choices	Description
`window_natvent_availability`	false	Days/week	Integer	auto	For operable windows, the number of days/week that windows can be opened by occupants for natural ventilation.

Table 70. The ResStock argument definitions set in the Windows characteristic (continued)

Name	Required	Units	Type	Choices	Description
`window_ufactor`	true	Btu/hr-ft^2-R	Double		Full-assembly National Fenestration Rating Council (NFRC) U-factor.
`window_shgc`	true		Double		Full-assembly NFRC solar heat gain coefficient.
`window_exterior_shading_winter`	false	Frac	Double	auto	Exterior shading coefficient for the winter season. 1.0 indicates no reduction in solar gain, 0.85 indicates 15% reduction, etc.
`window_exterior_shading_summer`	false	Frac	Double	auto	Exterior shading coefficient for the summer season. 1.0 indicates no reduction in solar gain, 0.85 indicates 15% reduction, etc.
`window_shading_summer_season`	false		String	auto	Enter a date like 'May 1 - Sep 30'. Defines the summer season for purposes of shading coefficients; the rest of the year is assumed to be winter.
`skylight_ufactor`	true	Btu/hr-ft^2-R	Double		Full-assembly NFRC U-factor.
`skylight_shgc`	true		Double		Full-assembly NFRC solar heat gain coefficient.
`skylight_storm_type`	false		Choice	auto, clear, low-e	The type of storm, if present. If not provided, assumes there is no storm.

Distribution Assumption(s)

- All Triple-Pane options assumed to be low-e.
- Only breaking out clear and low-e windows for the Double, Non-Metal frame type.
- Source of low-e distribution is based on engineering judgment, informed by high-level sales trends observed in Ducker Worldwide studies of the U.S. market for windows, doors and skylights.
- Due to low sample sizes, the following adjustments are made:
  - Vintage data are grouped into: (1) <1960, (2) 1960–79, (3) 1980–99, (4) 2000s, (5) 2010s.
  - Building Type data are grouped into: (1) Single-Family Detached, Single-Family Attached, and Mobile homes, and (2) Multifamily 2–4 units and Multifamily 5+ units.
  - Climate zones are grouped into:
    - 1A, 2A, 2B
    - 3A, 3B, 3C, 4B
    - 4A, 4C
    - 5A, 5B
    - 6A, 6B and
    - 7A, 7B 7AK, 8AK.
  - Federal Poverty Levels are progressively grouped together until all bins are combined.
  - Tenure options are progressively grouped together until all bins are combined.

- Storm window saturations are based on D&R International, Ltd. 2013. *Residential Windows and Window Coverings: A Detailed View of the Installed Base and User Behavior*. Cut the % storm windows by factor of 55% because only 55% of storms are installed year-round.
- Due to lack of performance data, Triple-Pane windows with storms are modeled without the storm windows.
- Due to lack of performance data, Double-Pane, Low-E, Non-Metal, Air, M-gain, and Exterior Clear Storm windows are modeled as Double-Pane, Clear, Non-Metal, Air, Exterior Clear Storm windows.

Window Areas

Description

Window-to-wall ratios for the front, back, left, and right walls.

Distribution Data Source(s)

- 2016–17 Residential Building Stock Assessment (RBSA) II microdata.

Direct Conditional Dependencies

- Geometry Building Type Height.

Option(s)

ResStock arguments use window-to-wall ratios to specify the window area instead of defining absolute window areas. Therefore, the following wall area constants are all set to zero in ResStock:

- `window_area_front` = 0
- `window_area_back` = 0
- `window_area_left` = 0
- `window_area_right` = 0
- `skylight_area_front` = 0
- `skylight_area_back` = 0
- `skylight_area_left` = 0
- `skylight_area_right` = 0.

ResStock has six different levels of window-to-wall ratios between 0.06 and 0.3 (Table 71). Window-to-wall ratios are assumed constant on all sides of the home.

Additionally, the `window_aspect_ratio` is set to 1.333 for all ResStock options.

Table 71. Window Area options and arguments that vary for each option

Option name	`window_front_wwr`	`window_back_wwr`	`window_left_wwr`	`window_right_wwr`
F6 B6 L6 R6	0.06	0.06	0.06	0.06
F9 B9 L9 R9	0.09	0.09	0.09	0.09
F12 B12 L12 R12	0.12	0.12	0.12	0.12
F15 B15 L15 R15	0.15	0.15	0.15	0.15
F18 B18 L18 R18	0.18	0.18	0.18	0.18
F30 B30 L30 R30	0.30	0.30	0.30	0.30

For the argument definitions, see Table 72. See the OpenStudio-HPXML Windows documentation for the available HPXML schema elements, default values, and constraints.

Table 72. The ResStock argument definitions set in the Window Area characteristic

Name	Required	Units	Type	Description
`window_front_wwr`	true	Frac	Double	The ratio of window area to wall area for the unit's front facade. Enter 0 if specifying Front Window Area instead.
`window_back_wwr`	true	Frac	Double	The ratio of window area to wall area for the unit's back facade. Enter 0 if specifying Back Window Area instead.
`window_left_wwr`	true	Frac	Double	The ratio of window area to wall area for the unit's left facade (when viewed from the front). Enter 0 if specifying Left Window Area instead.
`window_right_wwr`	true	Frac	Double	The ratio of window area to wall area for the unit's right facade (when viewed from the front). Enter 0 if specifying Right Window Area instead.
`window_area_front`	true	ft^2	Double	The amount of window area on the unit's front facade. Enter 0 if specifying Front Window-to-Wall Ratio instead.
`window_area_back`	true	ft^2	Double	The amount of window area on the unit's back facade. Enter 0 if specifying Back Window-to-Wall Ratio instead.
`window_area_left`	true	ft^2	Double	The amount of window area on the unit's left facade (when viewed from the front). Enter 0 if specifying Left Window-to-Wall Ratio instead.
`window_area_right`	true	ft^2	Double	The amount of window area on the unit's right facade (when viewed from the front). Enter 0 if specifying Right Window-to-Wall Ratio instead.
`window_aspect_ratio`	true	Frac	Double	Ratio of window height to width.
`skylight_area_front`	true	ft^2	Double	The amount of skylight area on the unit's front conditioned roof facade.
`skylight_area_back`	true	ft^2	Double	The amount of skylight area on the unit's back conditioned roof facade.
`skylight_area_left`	true	ft^2	Double	The amount of skylight area on the unit's left conditioned roof facade (when viewed from the front).
`skylight_area_right`	true	ft^2	Double	The amount of skylight area on the unit's right conditioned roof facade (when viewed from the front).

Distribution Assumption(s)

- The window-to-wall ratios (WWR) are exponential weibull distributed
- Multifamily with 2–4 Units distributions are independent of Geometry Stories
- Multifamily with 5+ Units distributions are grouped by 1–3 stories, 4–7 stories, and 8+ stories
- High-rise Multifamily buildings (8+ stories) have a 30% WWR
- SFD, SFA, and Mobile Homes are represented by the SFD window area distribution.

Overhangs

Description

Presence, depth, and location of window overhangs (not currently used in ResStock baseline).

Distribution Data Source(s)

- Not applicable.

Direct Conditional Dependencies

- None.

Option(s)

ResStock currently assumes all buildings have no overhang. Therefore, all models are assigned the option of “None” for this characteristic, and receive the following ResStock arguments:

- `overhangs_front_depth` = 0
- `overhangs_front_distance_to_top_of_window` = 0
- `overhangs_front_distance_to_bottom_of_window` = 4
- `overhangs_back_depth` = 0
- `overhangs_back_distance_to_top_of_window` = 0
- `overhangs_back_distance_to_bottom_of_window` = 4
- `overhangs_left_depth` = 0
- `overhangs_left_distance_to_top_of_window` = 0
- `overhangs_left_distance_to_bottom_of_window` = 4
- `overhangs_right_depth` = 0
- `overhangs_right_distance_to_top_of_window` = 0
- `overhangs_right_distance_to_bottom_of_window` = 4

For the argument definitions, see Table 73. See the OpenStudio-HPXML Overhangs documentation for the available HPXML schema elements, default values, and constraints.

Table 73. The ResStock argument definitions set in the Overhangs characteristic

Name	Required	Units	Type	Description
`overhangs_front_depth`	true	ft	Double	The depth of overhangs for windows for the front facade.
`overhangs_front_distance_to_top_of_window`	true	ft	Double	The overhangs distance to the top of window for the front facade.

Table 73. The ResStock argument definitions set in the Overhangs characteristic (continued)

Name	Required	Units	Type	Description
`overhangs_front_distance_to_bottom_of_window`	true	ft	Double	The overhangs distance to the bottom of window for the front facade.
`overhangs_back_depth`	true	ft	Double	The depth of overhangs for windows for the back facade.
`overhangs_back_distance_to_top_of_window`	true	ft	Double	The overhangs distance to the top of window for the back facade.
`overhangs_back_distance_to_bottom_of_window`	true	ft	Double	The overhangs distance to the bottom of window for the back facade.
`overhangs_left_depth`	true	ft	Double	The depth of overhangs for windows for the left facade.
`overhangs_left_distance_to_top_of_window`	true	ft	Double	The overhangs distance to the top of window for the left facade.
`overhangs_left_distance_to_bottom_of_window`	true	ft	Double	The overhangs distance to the bottom of window for the left facade.
`overhangs_right_depth`	true	ft	Double	The depth of overhangs for windows for the right facade.
`overhangs_right_distance_to_top_of_window`	true	ft	Double	The overhangs distance to the top of window for the right facade.
`overhangs_right_distance_to_bottom_of_window`	true	ft	Double	The overhangs distance to the bottom of window for the right facade.

Distribution Assumption(s)

- All homes are assumed to not have window overhangs (roof eaves are defined separately).

Eaves

Description

Depth of roof eaves.

Distribution Data Source(s)

- Building America House Simulation Protocols(Wilson, Engebrecht Metzger, et al. 2014).

Direct Conditional Dependencies

None.

Option(s)

All buildings receive the same value of 2 feet for `geometry_eaves_depth`.

For the argument definitions, see Table 74. See the OpenStudio-HPXML Enclosure documentation for the available HPXML schema elements, default values, and constraints.

Table 74. The ResStock argument definitions set in the Eaves characteristic

Name	Required	Units	Type	Choices	Description
`geometry_eaves_depth`	true	ft	Double		The eaves depth of the roof.

Distribution Assumption(s)

None.

Interior Shading

Description

Amount of window shading in the summer and winter.

Distribution Data Source(s)

- ANSI/RESNET/ICC 301 Standard.

Direct Conditional Dependencies

- None.

Option(s)

All models in ResStock receive the same shading option (Table 75).

Table 75. Interior Shading options and arguments that vary for each option

Option name	`window_interior_shading_winter`	`window_interior_shading_summer`
Summer = 0.7, Winter = 0.85	0.85	0.7

For the argument definitions, see Table 76. See the OpenStudio-HPXML Windows documentation for the available HPXML schema elements, default values, and constraints.

Table 76. The ResStock argument definitions set in the Interior Shading characteristic

Name	Required	Units	Type	Choices	Description
`window_interior_shading_winter`	false	Frac	Double	auto	Interior shading coefficient for the winter season. 1.0 indicates no reduction in solar gain, 0.85 indicates 15% reduction, etc.
`window_interior_shading_summer`	false	Frac	Double	auto	Interior shading coefficient for the summer season. 1.0 indicates no reduction in solar gain, 0.85 indicates 15% reduction, etc.

Distribution Assumption(s)

None.

8.3.5 Infiltration

Infiltration is air leakage between the envelope and the outdoor environment. In the U.S. residential sector, it is the leading driver of heating and cooling loads (compared to, for example, heat transfer through other parts of the envelope). In ResStock, infiltration is controlled by a single input file that provides a whole-home infiltration rate.

Infiltration

Description

Total infiltration to the dwelling unit.

Distribution Data Source(s)

- Distributions are based on the cumulative distribution functions from the Residential Diagnostics Database (ResDB).
- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Floor Area
- Vintage.

Option(s)

All infiltration options in ResStock are provided in air changes per hour (ACH) at 50 Pascals, as calculated by a blower door test. The characteristic sets the `air_leakage_leakiness_description`, `air_leakage_units`, `air_leakage_house_pressure`, `air_leakage_value`, `air_leakage_type`, and `site_shielding_of_home` ResStock arguments. For the argument definitions, see Table 77. See the OpenStudio-HPXML Site documentation for the available HPXML schema elements, default values, and constraints.

Table 77. The ResStock argument definitions set in the Infiltration characteristic

Name	Required	Units	Type	Choices	Description
`site_shielding_of_home`	false		Choice	auto, exposed, normal, well-shielded	Presence of nearby buildings, trees, obstructions for infiltration model.
`air_leakage_leakiness_description`	false		Choice	auto, very tight, tight, average, leaky, very leaky	Qualitative description of infiltration. If provided, the Year Built of the home is required. Either provide this input or provide a numeric air leakage value below.
`air_leakage_units`	true		Choice	ACH, CFM (cubic feet per minute), ACHnatural, CFMnatural, EffectiveLeakageArea	The unit of measure for the air leakage if providing a numeric air leakage value.
`air_leakage_house_pressure`	false	Pa	Double		The house pressure relative to outside if providing a numeric air leakage value. Required when units are ACH or CFM.
`air_leakage_value`	false		string		Numeric air leakage value. For 'EffectiveLeakageArea', provide value in sq. in. If provided, overrides Leakiness Description input.

Table 77. The ResStock argument definitions set in the Infiltration characteristic (continued)

Name	Required	Units	Type	Choices	Description
`air_leakage_type`	false		Choice	auto, unit total, unit exterior only	Type of air leakage. Type of air leakage if providing a numeric air leakage value. If 'unit total', represents the total infiltration to the unit as measured by a compartmentalization test, in which case the air leakage value will be adjusted by the ratio of exterior envelope surface area to total envelope surface area. Otherwise, if 'unit exterior only', represents the infiltration to the unit from outside only as measured by a guarded test. Required when unit type is single-family attached or apartment unit.

The options of the Infiltration characteristic range between 1 ACH 50 to 50 ACH 50 and set the `air_leakage_value` ResStock argument, Table 78.

Below is a list of arguments and their values that are constant across all the options.

- `air_leakage_leakiness_description` = auto
- `air_leakage_units` = ACH
- `air_leakage_house_pressure` = 50
- `air_leakage_type` = unit total
- `site_shielding_of_home` = normal

Table 78. Infiltration options and arguments that vary for each option

Option name	`air_leakage_value`
1 ACH50	1
2 ACH50	2
3 ACH50	3
4 ACH50	4
5 ACH50	5
6 ACH50	6
7 ACH50	7
8 ACH50	8
10 ACH50	10
15 ACH50	15
20 ACH50	20
25 ACH50	25
30 ACH50	30
40 ACH50	40
50 ACH50	50

Distribution Assumption(s)

- All ACH50 are based on Single-Family Detached blower door tests.
- Climate zones that are copied: 2A to 1A, 6A to 7A, and 6B to 7B.

- Vintage bins that are copied: 2000s to 2010s, 1950s to 1940s, 1950s to <1940s.
- Homes are assumed to not be Weatherization Assistance Program qualified and not ENERGY STAR certified.
- Climate zones 7AK and 8AK are averages of 6A and 6B.
- ResStock models multi-family and SFA units with the unit total air leakage type. The unit total air leakage assume that some of the sampled ACH50 value goes to neighboring units. The model infiltration value to the exterior is a smaller infiltration value that what is sampled and is adjusted by the ratio of exterior envelope surface area to total envelope surface area. The modeled infiltration to the exterior is reported in the results.
- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute proportionally between these two building types.
- For Alaska, Infiltration ACH50 values are calculated based on CFM50 from blower door test and estimated volume of the home.

8.4 HVAC

Heating, ventilating, and air conditioning (HVAC) is the leading driver of residential energy use in the United States. System configurations for providing these space-conditioning services vary, but can be related. The same equipment can provide both heating and cooling, there can be separate systems, or there can be multiple pieces of equipment providing the same service. In ResStock the input relationships between these files are complex because of these nuances and because of the structure of the surveys they're built upon. In this section, we'll cover the major HVAC types modeled in ResStock by service/component: Primary Heating, Secondary Heating, Cooling, Shared Systems, Setpoints, Ducts, HVAC Installation Quality, and Ventilation.

8.4.1 Primary Heating

Modeling Approach

In ResStock, many characteristics assign arguments for the primary heating systems. The first characteristic assigned is the Heating Fuel. ResStock currently models electricity, natural gas, propane, fuel oil, wood heating, and homes without heating systems. The next characteristic that drives most of the other heating characteristics is HVAC Heating Type, where the system is specified as ducted (example: forced air furnace), non-ducted (example: baseboard boiler) systems, ducted heat pump, and non-ducted heat pumps (example: mini-splits). ResStock models the following heating systems: a ducted air-source heat pump (ASHP), electric baseboard, boilers, furnaces, wall/floor furnaces, and mini-split heat pumps (MSHPs). For most of these systems there are also a range of efficiency levels (example: an 96% AFUE gas furnace and an 80% AFUE gas furnace; note that AFUE stands for Annual Fuel Utilization Efficiency).

For housing units in multifamily and single-family attached buildings, ResStock also has models for heating systems that are shared between 2 or more units. For heating systems that serve multiple housing units, see Section 8.4.4. For discussion about heating setpoints see Section 8.4.5.

Six input files specify the characteristics of the primary heating system:

- Heating Fuel
- HVAC Heating Type
- HVAC Heating Type and Fuel
- HVAC Heating Efficiency
- HVAC Has Zonal Electric Heating
- HVAC Heating Autosizing Factor.

The following sections discuss the characteristic distributions, data sources, conditional dependencies, options, assumptions, arguments, and argument values.

Heating Fuel

Description

The fuel used for primary heating of the housing unit.

Distribution Data Source(s)

- 2019 5-year PUMS
- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation.

Direct Conditional Dependencies

- County and PUMA
- Geometry Building Type RECS
- Vintage.

Options

The Heating Fuel characteristic options are Electricity, Natural Gas, Propane, Fuel Oil, None, Other Fuel, and Wood. Other Fuel is currently modeled as wood energy. However, although ResStock simulates wood energy consumption for heating, current datasets do not publish data on heating with wood. The characteristic sets the `heating_system_fuel` ResStock argument (Table 80). The argument definition for the `heating_system_fuel` argument is in Table 79.

See the OpenStudio-HPXML Heating Systems documentation for the available HPXML schema elements, default values, and constraints.

Table 79. The ResStock argument definitions set in the Heating Fuel characteristic

Name	Required	Units	Type	Choices	Description
`heating_system_fuel`	true		Choice	electricity, natural gas, fuel oil, propane, wood, wood pellets, coal	The fuel type of the heating system. Ignored for ElectricResistance.

Table 80. Heating Fuel options and arguments that vary for each option

Option name	`heating_system_fuel`
Electricity	electricity
Fuel Oil	fuel oil
Natural Gas	natural gas
None	natural gas
Other Fuel	wood
Propane	propane
Wood	wood

Distribution Assumption(s)

- In ACS, Heating Fuel is reported for occupied units only. By excluding Vacancy Status as a dependency, we assume vacant units share the same Heating Fuel distribution as occupied units. Where sample counts are less than 10, the State average distribution has been inserted. Prior to insertion, the following adjustments have been made to the state distribution so all rows have sample count > 10: 1. Where sample counts < 10 (which consists of Mobile Home and Single-Family Attached only), the Vintage ACS distribution is used instead of Vintage: [CT, DE, ID, MD, ME, MT, ND, NE, NH, NV, RI, SD, UT, VT, WY].

- Remaining Mobile Homes < 10 are replaced by Single-Family Detached + Mobile Homes combined: [DE, RI, SD, VT, WY, and all DC].
- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.
- For Alaska, all wood is modeled as cord wood.
- For Alaska, when heating uses more than one fuel, the fuel with highest consumption is considered the primary (heating) fuel, and fuel with second highest usage (provided it is at least 10% of total energy use across all fuels) is considered secondary (heating) fuel—except in case of electric heating, which is always assumed as primary. The rest of the fuels are ignored.

HVAC Heating Type

Description

The presence and type of the primary heating system in the housing unit.

Distribution Data Source(s)

- U.S. EIA 2020 RECS microdata
- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation.

Direct Conditional Dependencies

- Geometry Building Type RECS
- Heating Fuel
- State
- Vintage.

Options

The options for the HVAC Heating Type characteristic are Ducted Heat Pump, Ducted Heating, Non-Ducted Heat Pump, Non-Ducted Heating, and None. No ResStock arguments are assigned based upon these options; instead the HVAC Heating Type informs other HVAC inputs (such as HVAC Heating Efficiency) that do have related ResStock arguments.

Distribution Assumption(s)

- Due to low sample sizes, fallback rules lumped together the following: (1) Heating fuel lump: Fuel oil, Propane, Wood, and Other Fuel, (2) Geometry building SF: Mobile, Single-family attached, Single-family detached, (3) Geometry building MF: Multifamily with 2–4 Units, Multifamily with 5+ Units, and (4) Vintage Lump: 20-yr bins.
- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.

HVAC Heating Type and Fuel

Description

The presence, type, and fuel of primary heating system.

Distribution Data Source(s)

- Calculated directly from other distributions.

Direct Conditional Dependencies

- Heating Fuel
- HVAC Heating Efficiency.

Options

The options are a combination of the specific heating systems in HVAC Heating Efficiency characteristic and the Heating Fuel characteristic. The dependency combinations are directly mapped to the options in this characteristic. There are no ResStock arguments assigned directly from this input.

Distribution Assumption(s)

No assumptions were made.

HVAC Heating Efficiency

Description

The presence and efficiency of the primary heating system in the housing unit. This is the main input that determines the modeled heating system.

Distribution Data Source(s)

- The sample counts and sample weights are constructed using U.S. EIA 2020 RECS microdata.
- Shipment data based on ENERGY STAR ASHP shipments data and ENERGY STAR furnace shipments data. Efficiency data from Home Energy Saver are combined with age of equipment data from RECS.
- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation.

Direct Conditional Dependencies

- Custom State
- Heating Fuel
- HVAC Has Shared System
- HVAC Heating Type
- Vintage.

Options

The options of the HVAC Heating Efficiency characteristic assigns the heating system type and efficiency of the heating system. The system types are ducted ASHPs, electric baseboard, electric boiler, electric furnace, electric wall furnace, fuel boiler, fuel furnace, fuel wall/floor furnace, MSHPs, none, and shared heating. The Shared Systems option does not specify any arguments. Shared Systems designate heating systems that serve multiple housing units in a multifamily building, and they have their own characteristics that set the arguments; see Section 8.4.4. The HVAC Heating Efficiency characteristic sets the arguments listed in the argument definition table (Table 81). See the OpenStudio-HPXML Heating System documentation for the available HPXML schema elements, default values, and constraints.

The following arguments are always set to “auto” for all systems:

- `heating_system_heating_capacity`
- `heating_system_heating_autosizing_limit`

- `heat_pump_heating_capacity`
- `heat_pump_heating_autosizing_limit`
- `heat_pump_cooling_capacity`
- `heat_pump_cooling_autosizing_limit`
- `heat_pump_backup_heating_autosizing_limit`
- `heat_pump_backup_heating_capacity`
- `heat_pump_backup_sizing_methodology`
- `geothermal_loop_borefield_configuration`
- `geothermal_loop_loop_flow`
- `geothermal_loop_boreholes_count`
- `geothermal_loop_boreholes_length`
- `geothermal_loop_boreholes_spacing`
- `geothermal_loop_boreholes_diameter`
- `geothermal_loop_grout_type`
- `geothermal_loop_pipe_type`
- `geothermal_loop_pipe_diameter` and
- `heating_system_has_flue_or_chimney`.

The `heating_system_fraction_heat_load_served`, `heat_pump_fraction_heat_load_served`, `heat_pump_fraction_cool_load_served`, and `heat_pump_backup_heating_efficiency` arguments are always set to 1 for all systems.

The `heat_pump_heating_efficiency_type` is always HSPF (Heating Seasonal Performance Factor) for all systems. The `heat_pump_cooling_efficiency_type` is always SEER (Seasonal Energy Efficiency Ratio) for all systems. The `heat_pump_sizing_methodology` is always ACCA (Air Conditioning Contractors of America) for all systems in the ResStock baseline.

The `heat_pump_backup_use_existing_system` and `heat_pump_sizing_is_duct_limited` arguments are applicable for heat pump upgrades only. They are not used in baseline models.

Table 81. The ResStock argument definitions set in the HVAC Heating Efficiency characteristic

Name	Required	Units	Type	Choices	Description
`heating_system_type`	true		Choice	None, Furnace, WallFurnace, FloorFurnace, Boiler, ElectricResistance, Stove, SpaceHeater, Fireplace, Shared Boiler w/ Baseboard, Shared Boiler w/ Ductless Fan Coil	The type of heating system. Use 'none' if there is no heating system or if there is a heat pump serving a heating load.

Table 81. The ResStock argument definitions set in the HVAC Heating Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
`heating_system_heating_efficiency`	true	Frac	Double		The rated heating efficiency value of the heating system.
`heating_system_heating_capacity`	false	Btu/hr	Double		The output heating capacity of the heating system.
`heating_system_heating_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`heating_system_fraction_heat_load_served`	true	Frac	Double		The heating load served by the heating system.
`heating_system_pilot_light`	false	Btuh	Double		The fuel usage of the pilot light. Applies only to Furnace, WallFurnace, FloorFurnace, Stove, Boiler, and Fireplace with non-electric fuel type. If not provided, assumes no pilot light.
`heat_pump_type`	true		Choice	none, air-to-air, mini-split, ground-to-air, packaged terminal heat pump, room air conditioner with reverse cycle	The type of heat pump. Use 'none' if there is no heat pump.
`heat_pump_heating_efficiency_type`	true		Choice	HSPF, HSPF2, coefficient of performance (COP)	The heating efficiency type of heat pump. System types air-to-air and mini-split use HSPF or HSPF2. System types ground-to-air, packaged terminal heat pump, and room air conditioner with reverse cycle use COP.
`heat_pump_heating_efficiency`	true		Double		The rated heating efficiency value of the heat pump.
`heat_pump_cooling_efficiency_type`	true		Choice	SEER, SEER2, energy efficiency ratio (EER), combined energy efficiency ratio (CEER)	The cooling efficiency type of heat pump. System types air-to-air and mini-split use SEER or SEER2. System types ground-to-air, packaged terminal heat pump and room air conditioner with reverse cycle use EER.
`heat_pump_cooling_efficiency`	true		Double		The rated cooling efficiency value of the heat pump.

Table 81. The ResStock argument definitions set in the HVAC Heating Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
`heat_pump_cooling_compressor_type`	false		Choice	auto, single stage, two stage, variable speed	The compressor type of the heat pump. Only applies to air-to-air and mini-split. If not provided, the OS-HPXML default (see Air-to-Air Heat Pump, Mini-Split Heat Pump) is used.
`heat_pump_cooling_sensible_heat_fraction`	false	Frac	Double	auto	The sensible heat fraction of the heat pump. If not provided, the OS-HPXML default (see Air-to-Air Heat Pump, Mini-Split Heat Pump, Packaged Terminal Heat Pump, Room Air Conditioner w/ Reverse Cycle, Ground-to-Air Heat Pump) is used.
`heat_pump_heating_capacity`	false	Btu/hr	Double		The output heating capacity of the heat pump.
`heat_pump_heating_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`heat_pump_heating_capacity_retention_fraction`	false	Frac	Double	auto	The output heating capacity of the heat pump at a user-specified temperature (e.g., 17°F or 5°F) divided by the above nominal heating capacity. Applies to all heat pump types except ground-to-air.
`heat_pump_heating_capacity_retention_temp`	false	deg-F	Double		The user-specified temperature (e.g., 17°F or 5°F) for the above heating capacity retention fraction. Applies to all heat pump types except ground-to-air. Required if the Heating Capacity Retention Fraction is provided.
`heat_pump_cooling_capacity`	false	Btu/hr	Double		The output cooling capacity of the heat pump.
`heat_pump_cooling_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`heat_pump_fraction_heat_load_served`	true	Frac	Double		The heating load served by the heat pump.
`heat_pump_fraction_cool_load_served`	true	Frac	Double		The cooling load served by the heat pump.

Table 81. The ResStock argument definitions set in the HVAC Heating Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
`heat_pump_compressor_lockout_temp`	false	deg-F	Double	auto	The temperature below which the heat pump compressor is disabled. If both this and Backup Heating Lockout Temperature are provided and use the same value, it essentially defines a switchover temperature (for, e.g., a dual-fuel heat pump). Applies to all heat pump types other than ground-to-air.
`heat_pump_backup_type`	true		Choice	none, integrated, separate	The backup type of the heat pump. If 'integrated', represents e.g., built-in electric strip heat or dual-fuel integrated furnace. If 'separate', represents e.g., electric baseboard or boiler based on the Heating System 2 specified below. Use 'none' if there is no backup heating.
`heat_pump_backup_heating_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology if Backup Type is 'integrated'. If not provided, no limit is used. If Backup Type is 'separate', use Heating System 2: Heating Autosizing Limit.
`heat_pump_backup_fuel`	true		Choice	electricity, natural gas, fuel oil, propane	The backup fuel type of the heat pump. Only applies if Backup Type is 'integrated'.
`heat_pump_backup_heating_efficiency`	true		Double		The backup rated efficiency value of the heat pump. Percent for electricity fuel type. AFUE otherwise. Only applies if Backup Type is 'integrated'.
`heat_pump_backup_heating_capacity`	false	Btu/hr	Double		The backup output heating capacity of the heat pump. If not provided, the OS-HPXML autosized default (see Backup) is used. Only applies if Backup Type is 'integrated'.
`heat_pump_backup_heating_lockout_temp`	false	deg-F	Double	auto	The temperature above which the heat pump backup system is disabled. If both this and Compressor Lockout Temperature are provided and use the same value, it essentially defines a switchover temperature (for, e.g., a dual-fuel heat pump). Applies for both Backup Type of 'integrated' and 'separate'.

Table 81. The ResStock argument definitions set in the HVAC Heating Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
heat_pump_backup_use_existing_system	false		Boolean	true, false	Whether the heat pump uses the existing system as backup. This argument is only applicable for heat pump upgrades.
heat_pump_sizing_methodology	false		Choice	auto, ACCA, HERS, MaxLoad	The auto-sizing methodology to use when the heat pump capacity is not provided.
heat_pump_sizing_is_duct_limited	false		Boolean	true, false	Whether the (ducted) heat pump has an upper limit for autosized heating/cooling capacities and an adjusted blower fan (W/CFM) efficiency value. This argument is only applicable for heat pump upgrades.
heat_pump_backup_sizing_methodology	false		Choice	auto, emergency, supplemental	The auto-sizing methodology to use when the heat pump backup capacity is not provided.
heat_pump_is_ducted	false		Boolean	auto, true, false	Whether the heat pump is ducted or not. Only used for mini-split. It is assumed that air-to-air and ground-to-air are ducted, and packaged terminal heat pump and room air conditioner with reverse cycle are not ducted. If not provided, assumes not ducted.
heat_pump_crankcase_heater_watts	false	W	Double	auto	Heat pump crankcase heater power consumption in watts. Applies only to air-to-air, mini-split, packaged terminal heat pump, and room air conditioner with reverse cycle.
geothermal_loop_configuration	false		Choice	auto, none, vertical	Configuration of the geothermal loop. Only applies to ground-to-air heat pump type.
geothermal_loop_borefield_configuration	false		Choice	auto, rectangle, open rectangle, C, L, U, lopsided U	Borefield configuration of the geothermal loop. Only applies to ground-to-air heat pump type.
geothermal_loop_loop_flow	false	gpm	Double		Water flow rate through the geothermal loop. Only applies to ground-to-air heat pump type.
geothermal_loop_boreholes_count	false	#	Integer		Number of boreholes. Only applies to ground-to-air heat pump type. If not provided, the OS-HPXML autosized default (see HPXML Geothermal Loops) is used.
geothermal_loop_boreholes_length	false	ft	Double		Average length of each borehole (vertical). Only applies to ground-to-air heat pump type.

Table 81. The ResStock argument definitions set in the HVAC Heating Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
`geothermal_loop_boreholes_spacing`	false	ft	Double	auto	Distance between bores. Only applies to ground-to-air heat pump type.
`geothermal_loop_boreholes_diameter`	false	in	Double	auto	Diameter of bores. Only applies to ground-to-air heat pump type.
`geothermal_loop_grout_type`	false		Choice	auto, standard, thermally enhanced	Grout type of the geothermal loop. Only applies to ground-to-air heat pump type.
`geothermal_loop_pipe_type`	false		Choice	auto, standard, thermally enhanced	Pipe type of the geothermal loop. Only applies to ground-to-air heat pump type.
`geothermal_loop_pipe_diameter`	false	in	Choice	auto, 3/4" pipe, 1" pipe, 1-1/4" pipe	Pipe diameter of the geothermal loop. Only applies to ground-to-air heat pump type.
`heating_system_has_flue_or_chimney`	true		String		Whether the heating system has a flue or chimney.

For heat pump options and arguments that vary across the heat pump options, see Table 82. The `heating_system_type` argument is none, `heating_system_heating_efficiency` is 0 and not used. The `heat_pump_backup_type` is set to integrated. The `heating_system_pilot_light` argument is not specified. The `heat_pump_cooling_compressor_type`, `heat_pump_cooling_sensible_heat_fraction`, `heat_pump_heating_capacity`, `heat_pump_heating_autosizing_limit`, `heat_pump_compressor_lockout_temp`, `heat_pump_backup_heating_lockout_temp`, and `heat_pump_crankcase_heater_watts` are set to “auto.”

Table 82. HVAC Heating Efficiency heat pump options and arguments that vary for each option

Option name	`heat_pump_type`	`heat_pump_heating_efficiency`	`heat_pump_cooling_efficiency`	`heat_pump_heating_capacity_retention_fraction`	`heat_pump_heating_capacity_retention_temp`	`heat_pump_is_ducted`
ASHP, SEER 10, 6.2 HSPF	air-to-air	6.2	10	auto	auto	
ASHP, SEER 13, 7.7 HSPF	air-to-air	7.7	13	auto	auto	
ASHP, SEER 15, 8.5 HSPF	air-to-air	8.5	15	auto	auto	
MSHP, SEER 14.5, 8.2 HSPF	mini-split	8.2	14.5	0.25	-5	false
MSHP, SEER 29.3, 14 HSPF	mini-split	14	29.3	0.5	-15	false

For other heating systems the options and arguments that vary across these options, see Table 83. The `heat_pump_type` and the `heat_pump_backup_type` arguments are set to none. The `heat_pump_heating_efficiency` and `heat_pump_cooling_efficiency` arguments are set to 0 and are not used. The `heat_pump_cooling_compressor_type`, `heat_pump_cooling_sensible_heat_fraction`, `heat_pump_heating_capacity_retention_fraction`, `heat_pump_heating_capacity_retention_temp`, `heat_pump_compressor_lockout_temp`, `heat_pump_backup_heating_lockout_temp`, `heat_pump_is_ducted`, and `heat_pump_crankcase_heater_watts` are not set.

Table 83. HVAC Heating Efficiency non-heat pump heating system options and arguments that vary for each option

Option name	`heating_system_type`	`heating_system_heating_efficiency`	`heating_system_pilot_light`
Electric Baseboard, 100% Efficiency	ElectricResistance	1	
Electric Boiler, 100% AFUE	Boiler	1	
Electric Furnace, 100% AFUE	Furnace	1	
Electric Wall Furnace, 100% AFUE	WallFurnace	1	
Fuel Boiler, 76% AFUE	Boiler	0.76	auto
Fuel Boiler, 80% AFUE	Boiler	0.8	auto
Fuel Boiler, 90% AFUE	Boiler	0.9	auto
Fuel Furnace, 60% AFUE	Furnace	0.6	auto
Fuel Furnace, 76% AFUE	Furnace	0.76	auto
Fuel Furnace, 80% AFUE	Furnace	0.8	auto
Fuel Furnace, 83% AFUE	Furnace	0.83	auto
Fuel Furnace, 92.5% AFUE	Furnace	0.925	auto
Fuel Furnace, 95% AFUE	Furnace	0.95	auto
Fuel Wall/Floor Furnace, 60% AFUE	WallFurnace	0.6	auto
Fuel Wall/Floor Furnace, 68% AFUE	WallFurnace	0.68	auto
None	none	0	

Distribution Assumption(s)

- If a house has a wall furnace with fuel other than natural gas, the efficiency level based on natural gas from the Home Energy Saver weighted shipment efficiencies data is assigned.
- If a house has a heat pump with fuel other than electricity (presumed dual-fuel heat pump), the heating type is assumed to be furnace and not heat pump.
- The ENERGY STAR shipment volume for boiler was not available, so ENERGY STAR shipment volume for furnaces was used instead.

- Due to low sample size for some categories, the HVAC Has Shared System categories ‘Cooling Only’ and ‘None’ are combined for the purpose of querying Heating Efficiency distributions.
- For ‘other’ heating system types, we assign them to Electric Baseboard if fuel is Electric, and assign them to Wall/Floor Furnace if fuel is natural gas, fuel oil, or propane.
- For Other Fuel and Wood, the lowest efficiency systems are assumed.
- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.
- For Alaska, electric space heaters are modeled as electric baseboards.
- For Alaska, Toyo/monitor direct-vent devices and other fuel space heaters are not modeled.
- For Alaska, fireplace and stoves are not modeled.
- For Alaska, all heat pumps (including geothermal) are assumed to be non-ducted ASHPs.

HVAC Has Zonal Electric Heating

Description

Presence of electric baseboard heating.

Distribution Data Source(s)

- This characteristic is a direct mapping from the HVAC Heating Efficiency characteristic.

Direct Conditional Dependencies

- HVAC Heating Efficiency.

Options

The options for the HVAC Heating Efficiency are “Yes” and “No.” The system that is assigned the “Yes” option is Electric Baseboard, 100% Efficiency. All other systems are assigned the “No” option. No ResStock arguments are directly assigned from this input file.

Distribution Assumption(s)

No assumptions are made. The characteristic options are a direct map from the HVAC Heating Efficiency characteristic.

HVAC Heating Autosizing Factor

Description

The heating capacity and airflow scaling factor applied to the auto-sizing methodology. This is not currently used in baseline.

Distribution Data Source(s)

- Engineering judgment.

Direct Conditional Dependencies

- HVAC Heating Efficiency
- HVAC System is Scaled.

Options

There are two options in the baseline: "None" and "40% Oversized." Only the "None" option is used. HVAC sizing follows ACCA Manual J and Manual S. There is no additional oversizing or undersizing the capacity and airflow of the HVAC system. This capability is not currently being used in ResStock. The characteristic assigns the `heating_system_heating_autosizing_factor`, `heat_pump_heating_autosizing_factor`, `heat_pump_backup_heating_autosizing_factor`, and `heating_system_2_heating_autosizing_factor` ResStock arguments. All are left blank for the "None" option and are not used. For argument definitions see Table 84.

Table 84. The ResStock argument definitions set in the HVAC Heating Autosizing Factor characteristic

Name	Required	Units	Type	Choices	Description
`heating_system_heating_autosizing_factor`	false		Double		The capacity scaling factor applied to the auto-sizing methodology. If not provided, 1.0 is used.
`heat_pump_heating_autosizing_factor`	false		Double		The capacity scaling factor applied to the auto-sizing methodology. If not provided, 1.0 is used.
`heat_pump_backup_heating_autosizing_factor`	false		Double		The capacity scaling factor applied to the auto-sizing methodology if Backup Type is 'integrated'. If not provided, 1.0 is used. If Backup Type is 'separate', use Heating System 2: Heating Autosizing Factor.
`heating_system_2_heating_autosizing_factor`	false		Double		The capacity scaling factor applied to the auto-sizing methodology. If not provided, 1.0 is used.

Distribution Assumption(s)

No assumptions are made. The capability is not used.

8.4.2 Secondary Heating

Modeling Approach

Many homes use a secondary heating source in addition to their primary heating source. Common examples include electric space heaters or a wood stove. ResStock has the capability to include these secondary heating sources in upgrade scenarios. Currently only Alaska is modeled with any use of secondary heating in the baseline. At any given time step the heating load needs to be met. A fraction of this load is assigned to the secondary system. This approach has some limitations. The secondary system is typically a second system supplying heating. They are often turned on during the coldest times of the coldest periods and may be off for a good portion of the year. We currently do not model this behavior in ResStock.

The next sections discuss the building stock characteristic distributions, their options, assumptions, conditional dependencies, arguments, and argument values assigned in these characteristics.

HVAC Secondary Heating Type

Description

The efficiency and type of the secondary heating system.

Distribution Data Source(s)

- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by the Alaska Housing Finance Corporation. Not implemented in baseline for other states.

Direct Conditional Dependencies

- Custom State
- Geometry Building Type RECS
- HVAC Heating Type
- HVAC Secondary Heating Fuel
- Vintage.

Options

Only homes in Alaska have secondary heating, so most housing units receive a “None” assignment. No ResStock arguments are assigned from this input file.

Distribution Assumption(s)

- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.
- Ducted heating or heat pump cannot have ducted secondary heating.
- For Alaska, all heat pumps are assumed to be non-ducted mini-splits.
- For Alaska, electricity cannot be a secondary heating fuel, therefore no secondary heating type.

HVAC Secondary Heating Fuel

Description

Secondary Heating Fuel for the housing unit.

Distribution Data Source(s)

- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation. Secondary heating is not currently implemented in baseline for other states.

Direct Conditional Dependencies

- County
- Geometry Building Type RECS
- Vintage

Options

The options for the secondary heating fuel are the fuels used in the secondary HVAC system (Table 85).

Table 85. HVAC Secondary Heating Fuel options and arguments that vary for each option

Option name	`heating_system_2_fuel`
Electricity	electricity
Fuel Oil	fuel oil
Natural Gas	natural gas

Table 85. HVAC Secondary Heating Fuel options and arguments that vary for each option

Option name	`heating_system_2_fuel`
None	electricity
Other Fuel	wood
Propane	propane
Wood	wood

For the argument definitions, see Table 86. See the OpenStudio-HPXML heating systems documentation for the available HPXML schema elements, default values, and constraints.

Table 86. The ResStock argument definitions set in the HVAC Secondary Heating Fuel characteristic

Name	Required	Type	Choices	Description
`heating_system_2_fuel`	true	Choice	electricity, natural gas, fuel oil, propane, wood, wood pellets, coal	The fuel type of the second heating system. Ignored for ElectricResistance.

Distribution Assumption(s)

- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.
- For Alaska, all wood is modeled as cord wood.
- For Alaska, when heating uses more than one fuel, the fuel with highest consumption is considered the primary (heating) fuel, and fuel with second highest usage (provided it is at least 10% of total energy use across all fuels) is considered secondary (heating) fuel—except in case of electric heating, which is always assumed as primary (i.e., secondary heating fuel cannot be electricity). The rest of the fuels are ignored.

HVAC Secondary Heating Efficiency

Description

The efficiency of the secondary heating system.

Distribution Data Source(s)

- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation. Secondary heating is not currently implemented in baseline for other states.

Direct Conditional Dependencies

- Custom State
- Geometry Building Type RECS
- HVAC Secondary Heating Fuel
- Vintage.

Options

The options of the HVAC Secondary Heating Efficiency are the secondary heating system efficiency (Table 87). The Shared Heating option is used for Shared Heating. The "None" option is used for systems without secondary heating systems. The characteristic sets the following ResStock arguments to "auto": `heating_system_2_heating_capacity`, `heating_system_2_heating_autosizing_limit`, and `heating_system_2_has_flue_or_chimney`.

Table 87. HVAC Secondary Heating Efficiency options and arguments that vary for each option

Option name	`heating_system_2_type`	`heating_system_2_heating_efficiency`
Fuel Boiler, 76% AFUE	Boiler	0.76
Fuel Boiler, 80% AFUE	Boiler	0.8
Fuel Boiler, 90% AFUE	Boiler	0.90
Fuel Furnace, 60% AFUE	Furnace	0.6
Fuel Furnace, 76% AFUE	Furnace	0.76
Fuel Furnace, 80% AFUE	Furnace	0.8
Fuel Furnace, 92.5% AFUE	Furnace	0.925
None	none	0
Shared Heating	none	0

For the argument definitions, see Table 88. See the OpenStudio-HPXML Heating Systems documentation for the available HPXML schema elements, default values, and constraints.

Table 88. The ResStock argument definitions set in the HVAC Secondary Heating Efficiency characteristic

Name	Required	Units	Type	Choices	Description
`heating_system_2_type`	true		Choice	None, Furnace, WallFurnace, FloorFurnace, Boiler, ElectricResistance, Stove, SpaceHeater, Fireplace	The type of the second heating system. If a heat pump is specified and the backup type is 'separate', this heating system represents 'separate' backup heating. For ducted heat pumps where the backup heating system is a 'Furnace', the backup would typically be characterized as 'integrated' in that the furnace and heat pump share the same distribution system and blower fan; a 'Furnace' as 'separate' backup to a ducted heat pump is not supported.
`heating_system_2_heating_efficiency`	true	Frac	Double		The rated heating efficiency value of the second heating system.
`heating_system_2_heating_capacity`	false	Btu/hr	Double		The output heating capacity of the second heating system.
`heating_system_2_heating_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`heating_system_2_has_flue_or_chimney`	true		String		Whether the second heating system has a flue or chimney.

Distribution Assumption(s)

- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.
- For Alaska, electricity cannot be a secondary heating fuel, therefore no secondary heating efficiency.
- For Alaska, Toyo/monitor direct-vent devices and other fuel space heaters are not modeled.
- For Alaska, fireplace and stoves are not modeled.

HVAC Secondary Heating Partial Space Conditioning

Description

The fraction of heating load served by secondary heating system. The remainder is served by the primary heating system.

Distribution Data Source(s)

- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation. Secondary heating partial space conditioning is not currently implemented in baseline for other states.

Direct Conditional Dependencies

- Custom State
- HVAC Secondary Heating Fuel
- HVAC Secondary Heating Type
- Vintage.

Options

The options are the fraction of the load served for the secondary heating system (Table 89). The characteristic sets the `heating_system_2_fraction_heat_load_served` ResStock argument.

Table 89. HVAC Secondary Heating Partial Space Conditioning options and arguments that vary for each option

Option name	`heating_system_2_fraction_heat_load_served`
0%	0
10%	0.1
20%	0.2
30%	0.3
40%	0.4
49%	0.49

For the argument definitions, see Table 90. See the OpenStudio-HPXML Heating Systems documentation for the available HPXML schema elements, default values, and constraints.

Table 90. The ResStock argument definitions set in the HVAC Secondary Heating Partial Space Conditioning characteristic

Name	Required	Units	Type	Description
`heating_system_2_fraction_heat_load_served`	true	Frac	Double	The heat load served fraction of the second heating system. Ignored if this heating system serves as a backup system for a heat pump.

Distribution Assumption(s)

- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.
- For Alaska, the fraction of the load served by the secondary heating system is calculated as the ratio of annual energy used by secondary fuel and annual energy used by secondary and primary fuel.

8.4.3 Cooling

Modeling Approach

ResStock models various cooling equipment such as central air conditioners, room air conditioners, and heat pumps. Evaporative (swamp) coolers are an option as a cooling type but are not currently modeled. In ResStock, the cooling system is assigned after the heating system, so that if the heating system is a heat pump, the cooling system is also set to a heat pump. Central air conditioners are ducted systems; room air conditioners are equipment that often are in a window or mounted on the wall. Both room air conditioners and central air conditioners sometimes cool only a fraction of the floor area (more common with room air conditioners). This is represented by assigning a fraction of the cooling load to the cooling system. Heat pumps are assumed to serve the 100% of the cooling load. ResStock also varies the efficiency of the cooling system to represent newer, more efficient systems along with older, less efficient systems.

Three input files inform cooling system selection in ResStock:

- HVAC Cooling Type
- HVAC Cooling Efficiency
- HVAC Cooling Partial Space Conditioning.

Additionally, HVAC Cooling Autosizing Factor is related to cooling, but is not currently used in the ResStock baseline.

HVAC Cooling Type

Description

The presence and type of primary cooling system in the housing unit.

Distribution Data Source(s)

- U.S. EIA 2020 RECS microdata.
- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation.

Direct Conditional Dependencies

- Geometry Building Type RECS
- HVAC Heating Type
- State
- Vintage ACS.

Options

The options of HVAC Cooling Type are Central AC, Ducted Heat Pump, Evaporative or Swamp Cooler, Non-Ducted Heat Pump, None, and Room AC. The options do not assign any ResStock arguments but are used as dependencies in other characteristics.

Distribution Assumption(s)

- Due to low sample sizes, fallback rules were applied, with coarsening of (1) HVAC Heating type: Non-ducted heating and None, (2) Geometry building SF: Mobile, Single-family attached, Single-family detached, (3) Geometry building MF: Multifamily with 2–4 Units, Multifamily with 5+ Units, (4) Vintage Lump: 20-yr bins.
- Homes having ducted heat pump for heating and electricity fuel are assumed to have ducted heat pump for cooling (separating from central AC category).
- Homes having non-ducted heat pump for heating are assumed to have non-ducted heat pump for cooling.

- For Hawaii, central air conditioning saturation is from RECS 2020 by heating type, ignoring all other dependencies
- For Hawaii, Non-Ducted Heat Pump saturation is underestimated because ResStock does not currently allow cooling-only Non-Ducted Heat Pumps. These samples are modeled as Room ACs
- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.
- For Alaska, we are not modeling any central and room AC.
- For Alaska, cooling systems are never shared.
- Hawaii does not follow the same fallback rules. All distributions are custom adjusted so that state-level central air-conditioning saturation matches the state-level saturation in RECS2020.

HVAC Cooling Efficiency

Description

The presence and efficiency of primary cooling system in the housing unit. In the assumptions heat pumps (both ducted and non ducted) are assumed to serve for both heating and cooling. In the RECS2020 survey that cooling and heating technologies are based on, it was recently discoved that some samples reported None for heating, but heat pump for cooling (especialy non-ducted heat pumps). This is especially prevalent in hot climates with low cooling saturation. In ResStock, those samples with None heating and non ducted heat pump cooling in the survey are currently not being counted as having heat pumps. This is a known issue that will be addressed in a future release. In Hawaii, where this issue is most prevalent, the Room AC saturation has been increased to account for the undercounting of non-ducted heat pumps.

Distribution Data Source(s)

- The sample counts and sample weights are constructed using U.S. EIA 2020 RECS microdata
- Efficiency data based on ENERGY STAR shipment and Home Energy Saver data combined with age of equipment data from RECS 2020.

Direct Conditional Dependencies

- HVAC Cooling Type
- HVAC Has Shared System
- Vintage.

Options

ResStock includes four options for central air conditioners and four options for room air conditioners (Table 91). If a building has a heat pump, it is assumed that the heat pump is serving both the heating and cooling load. Buildings with heat pumps assigned in the HVAC Heating input files are flagged, but no ResStock arguments are passed to those building based on this file. Similarly, homes with a shared cooling system for the building are flagged, but the ResStock arguments for that system are assigned in the HVAC Shared Systems Efficiencies characteristic.

Across options with ResStock arguments, many are the same and set to *auto*:

- `cooling_system_cooling_compressor_type`
- `cooling_system_cooling_sensible_heat_fraction`
- `cooling_system_cooling_capacity`
- `cooling_system_cooling_autosizing_limit`
- `cooling_system_crankcase_heater_watts`
- `cooling_system_integrated_heating_system_fuel`

- `cooling_system_integrated_heating_system_efficiency_percent`
- `cooling_system_integrated_heating_system_capacity`
- `cooling_system_integrated_heating_system_fraction_heat_load_served`.

Additionally, `cooling_system_is_ducted` is set to false since ducts are defined in separate input files, and mini-split heat pumps will not be assigned ducts.

Table 91. HVAC Cooling Efficiency options and arguments that vary for each option

Option name	`cooling_system_type`	`cooling_system_cooling_efficiency_type`	`cooling_system_cooling_efficiency`
AC, SEER 8	central air conditioner	SEER	8
AC, SEER 10	central air conditioner	SEER	10
AC, SEER 13	central air conditioner	SEER	13
AC, SEER 15	central air conditioner	SEER	15
Ducted Heat Pump	none	SEER	0
Non-Ducted Heat Pump	none	SEER	0
None	none	SEER	0
Room AC, EER 8.5	room air conditioner	EER	8.5
Room AC, EER 9.8	room air conditioner	EER	9.8
Room AC, EER 10.7	room air conditioner	EER	10.7
Room AC, EER 12.0	room air conditioner	EER	12
Shared Cooling			

For the argument definitions, see Table 92. See the OpenStudio-HPXML Cooling Systems documentation for the available HPXML schema elements, default values, and constraints.

Table 92. The ResStock argument definitions set in the HVAC Cooling Efficiency characteristic

Name	Required	Units	Type	Choices	Description
`cooling_system_type`	true		Choice	none, central air conditioner, room air conditioner, evaporative cooler, mini-split, packaged terminal air conditioner	The type of cooling system. Use 'none' if there is no cooling system or if there is a heat pump serving a cooling load.
`cooling_system_cooling_efficiency_type`	true		Choice	SEER, SEER2, EER, CEER	The efficiency type of the cooling system. System types central air conditioner and mini-split use SEER or SEER2. System types room air conditioner and packaged terminal air conditioner use EER or CEER. Ignored for system type evaporative cooler.
`cooling_system_cooling_efficiency`	true		Double		The rated efficiency value of the cooling system. Ignored for evaporative cooler.

Table 92. The ResStock argument definitions set in the HVAC Cooling Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
`cooling_system_cooling_compressor_type`	false		Choice	auto, single stage, two stage, variable speed	The compressor type of the cooling system. Only applies to central air conditioner and mini-split.
`cooling_system_cooling_sensible_heat_fraction`	false	Frac	Double	auto	The sensible heat fraction of the cooling system. Ignored for evaporative cooler.
`cooling_system_cooling_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`cooling_system_is_ducted`	false		Boolean	auto, true, false	Whether the cooling system is ducted or not. Only used for mini-split and evaporative cooler. It's assumed that central air conditioner is ducted, and room air conditioner and packaged terminal air conditioner are not ducted.
`cooling_system_crankcase_heater_watts`	false	W	Double	auto	Cooling system crankcase heater power consumption in watts. Applies only to central air conditioner, room air conditioner, packaged terminal air conditioner and mini-split.
`cooling_system_integrated_heating_system_fuel`	false		Choice	auto, electricity, natural gas, fuel oil, propane, wood, wood pellets, coal	The fuel type of the heating system integrated into cooling system. Only used for packaged terminal air conditioner and room air conditioner.
`cooling_system_integrated_heating_system_efficiency_percent`	false	Frac	Double		The rated heating efficiency value of the heating system integrated into cooling system. Only used for packaged terminal air conditioner and room air conditioner.
`cooling_system_integrated_heating_system_capacity`	false	Btu/hr	Double		The output heating capacity of the heating system integrated into cooling system.

Table 92. The ResStock argument definitions set in the HVAC Cooling Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
`cooling_system_integrated_heating_system_fraction_heat_load_served`	false	Frac	Double		The heating load served by the heating system integrated into cooling system. Only used for packaged terminal air conditioner and room air conditioner.

Distribution Assumption(s)

None

HVAC Cooling Partial Space Conditioning

Description

The fraction of cooling load served by the cooling system. This is approximately equal to the fraction of finished floor area served by the cooling system. Cooling load must be met at every time step for the portion of floor area covered, and does not represent intermittent cooling overtime.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata in Hawaii.
- Constructed using U.S. EIA 2009 RECS microdata in all locations except Hawaii.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004—Sub-CZ Split
- Geometry Building Type RECS
- Geometry Floor Area Bin
- HVAC Cooling Type.

Options

Six different levels of percent of floor area cooled are provided, plus an option for homes that have no cooling (Table 93).

Table 93. HVAC Cooling Partial Space Conditioning options and arguments that vary for each option

Option name	`cooling_system_fraction_cool_load_served`
<10% Conditioned	0.1
20% Conditioned	0.2
40% Conditioned	0.4
60% Conditioned	0.6
80% Conditioned	0.8
100% Conditioned	1
None	0

For the argument definitions, see Table 94. See the OpenStudio-HPXML Cooling-Systems documentation for the available HPXML schema elements, default values, and constraints.

Table 94. The ResStock argument definitions set in the HVAC Cooling Partial Conditioning characteristic

Name	Required	Units	Type	Description
`cooling_system_fraction_cool_load_served`	true	Frac	Double	The cooling load served by the cooling system.

Distribution Assumption(s)

- Central AC systems need to serve at least 60% of the floor area.
- Heat pumps serve 100% of the floor area in all locations except Hawaii because the system serves 100% of the heated floor area. Partial cooling is common in cooling dominated climate.
- Due to low sample count, this input is constructed by downscaling a core sub-input file with 3 sub-input files of different dependencies. The sub-input files have the following dependencies:
  - input1 : 'HVAC Cooling Type', 'ASHRAE IECC Climate Zone 2004—Sub-CZ Split'
  - input2 : 'HVAC Cooling Type', 'Geometry Floor Area Bin'
  - input3 : 'HVAC Cooling Type', 'Geometry Building Type RECS'

HVAC Cooling Autosizing Factor

Description

The cooling capacity and airflow scaling factor applied to the auto-sizing methodology. Not currently used in baseline.

Distribution Data Source(s)

- N/A.

Direct Conditional Dependencies

- HVAC Cooling Efficiency
- HVAC System is Scaled.

Options

Since this input file is not currently used, all homes are set to an option of "None."

For the argument definitions, see Table 95. See the OpenStudio-HPXML Cooling Systems documentation for the available HPXML schema elements, default values, and constraints.

Table 95. The ResStock argument definitions set in the HVAC Cooling Autosizing Factor characteristic

Name	Required	Type	Description
`cooling_system_cooling_autosizing_factor`	false	Double	The capacity scaling factor applied to the auto-sizing methodology. If not provided, 1.0 is used.
`heat_pump_cooling_autosizing_factor`	false	Double	The capacity scaling factor applied to the auto-sizing methodology. If not provided, 1.0 is used.

Distribution Assumption(s)
HVAC sizing follows ACCA Manual J and Manual S. There is no additional oversizing or undersizing the capacity and airflow of the HVAC system.

8.4.4 Shared Systems

Modeling Approach

Shared systems in ResStock are heating and cooling systems that provide heating or cooling to more than one housing unit in a single-family attached or multifamily building. The types of systems that we model are boiler baseboard and fan coil systems. This is an area flagged for future improvement since more complex systems exist in reality, including systems that provide both heating and hot water. The shared systems currently in ResStock can provide heating, cooling, or heating and cooling to the unit. The boiler baseboard systems are heating-only systems. Fan coil systems that only provide cooling are modeled as a mini-split heat pump in ResStock. In reality, these systems are fan coils connected to central chillers. Fan coils that provide heating and cooling are modeled as a shared boiler with a ductless fan coil in ResStock. Currently, in ResStock these shared systems are modeled as equivalent in-unit systems (with adjusted efficiencies), not shared systems connected to multiple housing units (this may change in the future). As a result central distribution losses associated with supplying the water to multiple units are not currently captured in ResStock's shared system modeling.

Four input files determine the options and arguments for ResStock shared systems:

- HVAC Has Shared System
- HVAC Shared Efficiencies
- HVAC System is Faulted
- HVAC System is Scaled.

HVAC Has Shared System

Description
The presence of an HVAC system shared by multiple housing units.

Distribution Data Source(s)

- The sample counts and sample weights are constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Geometry Building Type RECS
- HVAC Cooling Type
- HVAC Heating Type
- Vintage.

Options
Homes can be assigned to have shared cooling, shared heating, shared both heating and cooling, or no shared systems. No ResStock arguments are assigned based on this input file, but these options are used as dependencies in other ResStock input files, such as HVAC Shared Efficiencies, where arguments are assigned.

Distribution Assumption(s)

- Due to low sample sizes, the fallback rules are applied in following order:
  1. Vintage: Vintage ACS 20-year bin
  2. HVAC Cooling Type: Lump (1) Central AC and Ducted Heat Pump, and (2) Non-Ducted Heat Pump and None

3. HVAC Heating Type: Lump (1) Ducted Heating and Ducted Heat Pump, and (2) Non-Ducted Heat Pump and None
4. HVAC Cooling Type: Lump (1) Central AC and Ducted Heat Pump, and (2) Non-Ducted Heat Pump, Non-Ducted Heating, and None
5. HVAC Heating Type: Lump (1) Ducted Heating and Ducted Heat Pump, and (2) Non-Ducted Heat Pump, None, and Room AC
6. Vintage: Vintage pre-1960s and post 2000
7. Vintage: All vintages

- Ducted Heat Pump option (a non-shared system) assigned for both heating and cooling
- Non-Ducted Heat Pump option (a non-shared system) assigned for both heating and cooling.

HVAC Shared Efficiencies

Description

The efficiency of a shared HVAC system.

Distribution Data Source(s)

- The sample counts and sample weights are constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Heating Fuel
- HVAC Has Shared System

Options

For homes with shared systems, ResStock models one option for Cooling-Only shared systems (Fan Coil, Cooling Only); two options for heating-only shared systems (Boiler Baseboards Heating Only, Electricity; and Boiler Baseboards Heating Only, Fuel); and two options for homes that have both heating and cooling shared (Fan Coil Heating and Cooling, Electricity; Fan Coil Heating and Cooling, Fuel). 89% of homes have no shared system.

For homes that have only a cooling shared system (and in-unit heating or no heating), this in nominally labeled as Fan Coil, Cooling only. However, ResStock currently approximates this as a mini-split heat pump instead of modeling a Fan Coil. The ResStock arguments for the placeholder are:

- `cooling_system_type`: mini-split
- `cooling_system_cooling_efficiency_type`: SEER
- `cooling_system_cooling_efficiency`: 13
- `cooling_system_cooling_capacity`: auto
- `cooling_system_cooling_autosizing_limit`: false
- `cooling_system_cooling_efficiency_type`: auto
- `cooling_system_is_ducted`: false

For homes with only heating shared (with cooling either in-unit or not installed), ResStock models two shared boilers with different fuel types (note: the `heating_system_fuel` argument is set by the Heating Fuel input file, which is why it's not listed here).

The following arguments are constant across both options:

- `heating_system_heating_capacity`: auto
- `heating_system_heating_autosizing_limit`: auto

- `heating_system_fraction_heat_load_served`: 1
- `heating_system_has_flue_or_chimney`: auto.

Additionally, the shared heating system doesn't use an air-source or geothermal heat pump, or a heat pump backup, but the following arguments are supplied since they are required arguments:

- `heat_pump_heating_efficiency_type`: none
- `heat_pump_heating_efficiency`: HSPF
- `heat_pump_cooling_efficiency_type`: 0
- `heat_pump_cooling_efficiency`: SEER
- `heat_pump_heating_capacity`: 0
- `heat_pump_heating_autosizing_limit`: auto
- `heat_pump_cooling_capacity`: auto
- `heat_pump_cooling_autosizing_limit`: auto
- `heat_pump_fraction_heat_load_served`: 1
- `heat_pump_fraction_cool_load_served`: 1
- `heat_pump_backup_type`: none
- `heat_pump_backup_heating_autosizing_limit`: auto
- `heat_pump_backup_fuel`: electricity
- `heat_pump_backup_heating_efficiency`: 1
- `heat_pump_backup_heating_capacity`: auto
- `heat_pump_sizing_methodology`: ACCA
- `heat_pump_backup_sizing_methodology`: auto
- `geothermal_loop_configuration`: none
- `geothermal_loop_borefield_configuration`: auto
- `geothermal_loop_loop_flow`: auto
- `geothermal_loop_boreholes_count`: auto
- `geothermal_loop_boreholes_length`: auto
- `geothermal_loop_boreholes_spacing`: auto
- `geothermal_loop_boreholes_diameter`: auto
- `geothermal_loop_grout_type`: auto
- `geothermal_loop_pipe_type`: auto
- `geothermal_loop_pipe_diameter`: auto.

Table 96. The ResStock argument definitions set in the HVAC Shared Efficiencies characteristic for Shared Heating

Option name	`heating_system_type`	`heating_system_heating_efficiency`
Boiler Baseboards Heating Only, Electricity	Shared Boiler w/ Baseboard	1

Table 96. The ResStock argument definitions set in the HVAC Shared Efficiencies characteristic for Shared Heating

Option name	`heating_system_type`	`heating_system_heating_efficiency`
Boiler Baseboards Heating Only, Fuel	Shared Boiler w/ Baseboard	0.78

For homes that have both heating and cooling shared, the arguments are a combination of the homes with shared cooling and the homes with shared heating. These options are labeled Fan Coil Heating and Cooling, but they are modeled as a central boiler and a mini-split heat pump. The following options are constant across both options:

Heating arguments:

- `heating_system_heating_capacity`: auto
- `heating_system_heating_autosizing_limit`: auto
- `heating_system_fraction_heat_load_served`: 1
- `heating_system_has_flue_or_chimney`: auto.

Cooling arguments:

- `cooling_system_type` mini-split
- `cooling_system_cooling_efficiency_type` SEER
- `cooling_system_cooling_efficiency` 13
- `cooling_system_cooling_capacity` auto
- `cooling_system_cooling_autosizing_limit` false
- `cooling_system_is_ducted` none.

Required but unused heating arguments:

- `heat_pump_type`: HSPF
- `heat_pump_heating_efficiency_type`: 0
- `heat_pump_heating_efficiency`: SEER
- `heat_pump_cooling_efficiency_type`: 0
- `heat_pump_cooling_efficiency`: auto
- `heat_pump_heating_capacity`: auto
- `heat_pump_heating_autosizing_limit`: auto
- `heat_pump_cooling_capacity`: auto
- `heat_pump_cooling_autosizing_limit`: auto
- `heat_pump_fraction_heat_load_served`: 1
- `heat_pump_fraction_cool_load_served`: 1
- `heat_pump_backup_type`: none
- `heat_pump_backup_heating_autosizing_limit`: auto
- `heat_pump_backup_fuel`: electricity
- `heat_pump_backup_heating_efficiency`: 1

- `heat_pump_backup_heating_capacity`: auto
- `heat_pump_sizing_methodology`: ACCA
- `heat_pump_backup_sizing_methodology`: auto
- `geothermal_loop_configuration`: none
- `geothermal_loop_borefield_configuration`: auto
- `geothermal_loop_loop_flow`: auto
- `geothermal_loop_boreholes_count`: auto
- `geothermal_loop_boreholes_length`: auto
- `geothermal_loop_boreholes_spacing`: auto
- `geothermal_loop_boreholes_diameter`: auto
- `geothermal_loop_grout_type`: auto
- `geothermal_loop_pipe_type`: auto
- `geothermal_loop_pipe_diameter`: auto.

Table 97. The ResStock argument definitions set in the HVAC Shared Efficiencies characteristic for Shared Heating and Cooling

Option name	Stock saturation	`heating_system_type`	`heating_system_heating_efficiency`
Fan Coil Heating and Cooling, Electricity	1.3%	Shared Boiler w/ Ductless Fan Coil	1
Fan Coil Heating and Cooling, Fuel	1.1%	Shared Boiler w/ Ductless Fan Coil	0.78

For the argument definitions, see Table 98. See the OpenStudio-HPXML Boiler-Shared or Mini-Split Heat Pumps documentation for the available HPXML schema elements, default values, and constraints.

Table 98. The ResStock argument definitions set in the HVAC Shared Efficiencies characteristic

Name	Required	Units	Type	Choices	Description
`heating_system_type`	true		Choice	none, Furnace, WallFurnace, FloorFurnace, Boiler, ElectricResistance, Stove, SpaceHeater, Fireplace, Shared Boiler w/ Baseboard, Shared Boiler w/ Ductless Fan Coil	The type of heating system. Use 'none' if there is no heating system or if there is a heat pump serving a heating load.
`heating_system_heating_efficiency`	true	Frac	Double		The rated heating efficiency value of the heating system.
`heating_system_heating_capacity`	false	Btu/hr	Double		The output heating capacity of the heating system.

Table 98. The ResStock argument definitions set in the HVAC Shared Efficiencies characteristic (continued)

Name	Required	Units	Type	Choices	Description
`heating_system_heating_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`heating_system_fraction_heat_load_served`	true	Frac	Double		The heating load served by the heating system.
`cooling_system_type`	true		Choice	none, central air conditioner, room air conditioner, evaporative cooler, mini-split, packaged terminal air conditioner	The type of cooling system. Use 'none' if there is no cooling system or if there is a heat pump serving a cooling load.
`cooling_system_cooling_efficiency_type`	true		Choice	SEER, SEER2, EER, CEER	The efficiency type of the cooling system. System types central air conditioner and mini-split use SEER or SEER2. System types room air conditioner and packaged terminal air conditioner use EER or CEER. Ignored for system type evaporative cooler.
`cooling_system_cooling_efficiency`	true		Double		The rated efficiency value of the cooling system. Ignored for evaporative cooler.
`cooling_system_cooling_capacity`	false	Btu/hr	Double		The output cooling capacity of the cooling system.
`cooling_system_cooling_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`cooling_system_is_ducted`	false		Boolean	auto, true, false	Whether the cooling system is ducted or not. Only used for mini-split and evaporative cooler. It’s assumed that central air conditioner is ducted, and room air conditioner and packaged terminal air conditioner are not ducted.

Table 98. The ResStock argument definitions set in the HVAC Shared Efficiencies characteristic (continued)

Name	Required	Units	Type	Choices	Description
`heat_pump_type`	true		Choice	none, air-to-air, mini-split, ground-to-air, packaged terminal heat pump, room air conditioner with reverse cycle	The type of heat pump. Use 'none' if there is no heat pump.
`heat_pump_heating_efficiency_type`	true		Choice	HSPF, HSPF2, COP	The heating efficiency type of heat pump. System types air-to-air and mini-split use HSPF or HSPF2. System types ground-to-air, packaged terminal heat pump, and room air conditioner with reverse cycle use COP.
`heat_pump_heating_efficiency`	true		Double		The rated heating efficiency value of the heat pump.
`heat_pump_cooling_efficiency_type`	true		Choice	SEER, SEER2, EER, CEER	The cooling efficiency type of heat pump. System types air-to-air and mini-split use SEER or SEER2. System types ground-to-air, packaged terminal heat pump and room air conditioner with reverse cycle use EER.
`heat_pump_cooling_efficiency`	true		Double		The rated cooling efficiency value of the heat pump.
`heat_pump_heating_capacity`	false	Btu/hr	Double		The output heating capacity of the heat pump.
`heat_pump_heating_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`heat_pump_cooling_capacity`	false	Btu/hr	Double		The output cooling capacity of the heat pump.
`heat_pump_cooling_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology. If not provided, no limit is used.
`heat_pump_fraction_heat_load_served`	true	Frac	Double		The heating load served by the heat pump.

Table 98. The ResStock argument definitions set in the HVAC Shared Efficiencies characteristic (continued)

Name	Required	Units	Type	Choices	Description
`heat_pump_fraction_cool_load_served`	true	Frac	Double		The cooling load served by the heat pump.
`heat_pump_backup_type`	true		Choice	none, integrated, separate	The backup type of the heat pump. If 'integrated', represents, e.g., built-in electric strip heat or dual-fuel integrated furnace. If 'separate', represents, e.g., electric baseboard or boiler based on the Heating System 2 specified below. Use 'none' if there is no backup heating.
`heat_pump_backup_heating_autosizing_limit`	false	Btu/hr	Double		The maximum capacity limit applied to the auto-sizing methodology if Backup Type is 'integrated'. If not provided, no limit is used. If Backup Type is 'separate', use Heating System 2: Heating Autosizing Limit.
`heat_pump_backup_fuel`	true		Choice	electricity, natural gas, fuel oil, propane	The backup fuel type of the heat pump. Only applies if Backup Type is 'integrated'.
`heat_pump_backup_heating_efficiency`	true		Double		The backup rated efficiency value of the heat pump. Percent for electricity fuel type. AFUE otherwise. Only applies if Backup Type is 'integrated'.
`heat_pump_backup_heating_capacity`	false	Btu/hr	Double		The backup output heating capacity of the heat pump. Only applies if Backup Type is 'integrated'.
`heat_pump_sizing_methodology`	false		Choice	auto, ACCA, HERS, MaxLoad	The auto-sizing methodology to use when the heat pump capacity is not provided.
`heat_pump_backup_sizing_methodology`	false		Choice	auto, emergency, supplemental	The auto-sizing methodology to use when the heat pump backup capacity is not provided.

Table 98. The ResStock argument definitions set in the HVAC Shared Efficiencies characteristic (continued)

Name	Required	Units	Type	Choices	Description
`geothermal_loop_configuration`	false		Choice	auto, none, vertical	Configuration of the geothermal loop. Only applies to ground-to-air heat pump type.
`geothermal_loop_borefield_configuration`	false		Choice	auto, rectangle, open rectangle, C, L, U, lopsided U	Borefield configuration of the geothermal loop. Only applies to ground-to-air heat pump type.
`geothermal_loop_loop_flow`	false	gpm	Double		Water flow rate through the geothermal loop. Only applies to ground-to-air heat pump type.
`geothermal_loop_boreholes_count`	false	#	Integer		Number of boreholes. Only applies to ground-to-air heat pump type.
`geothermal_loop_boreholes_length`	false	ft	Double		Average length of each borehole (vertical). Only applies to ground-to-air heat pump type.
`geothermal_loop_boreholes_spacing`	false	ft	Double	auto	Distance between bores. Only applies to ground-to-air heat pump type.
`geothermal_loop_boreholes_diameter`	false	in	Double	auto	Diameter of bores. Only applies to ground-to-air heat pump type.
`geothermal_loop_grout_type`	false		Choice	auto, standard, thermally enhanced	Grout type of the geothermal loop. Only applies to ground-to-air heat pump type.
`geothermal_loop_pipe_type`	false		Choice	auto, standard, thermally enhanced	Pipe type of the geothermal loop. Only applies to ground-to-air heat pump type.
`geothermal_loop_pipe_diameter`	false	in	Choice	auto, 3/4" pipe, 1" pipe, 1-1/4" pipe	Pipe diameter of the geothermal loop. Only applies to ground-to-air heat pump type.
`heating_system_has_flue_or_chimney`	true		String		Whether the heating system has a flue or chimney.

Distribution Assumption(s)

- Assume that all Heating and Cooling shared systems are fan coils in each housing unit served by a central chiller and boiler.

- Assume all Heating Only shared systems are hot water baseboards in each housing unit served by a central boiler.
- Assume all Cooling Only shared systems are fan coils in each housing unit served by a central chiller.

8.4.5 Setpoints

Setpoints Modeling Approach

There are a set of characteristics that assign heating and cooling setpoint schedules in ResStock. The characteristics assign the setpoint, whether there is a setpoint offset, the magnitude of the setpoint offset, and the offset period. The heating and cooling setpoints determine the temperature past which heating and cooling systems run to condition the home. They can vary over time as occupants change their thermostat settings, often choosing different settings overnight or when they are away from home. The setpoint offset specifies whether there is a change in the setpoint at any point during the day. An example would be a heating setback where the heating setpoint temperature is decreased during the day when no one is home. The offset magnitude is the number of degrees of the offset. The offset period determines what hours of the day the offset applies.

Every housing unit is assigned a heating setpoint and cooling setpoint, regardless of whether it has a heating system or a cooling system. If a sampled heating setpoint is greater than the cooling setpoint, the values are averaged and kept constant across heating and cooling seasons. Every housing unit is also assigned heating setpoint offsets, cooling setpoint offsets, or neither, and an offset magnitude and time period for any offsets it is assigned. The reason for the assignment of setpoint schedules for housing units without either heating or cooling systems is mainly for upgrades, as a diverse set of setpoint schedules can be applied to the unit without complicated upgrade apply logic. Another interpretation is that these setpoint schedules would be the preference of the housing units if they had a heating or cooling system.

The following describes the building stock characteristic distributions, their data sources, options, argument values, and assumptions.

Heating Setpoint

Description

Base heating setpoint (prior to any offset applied).

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Building Type RECS
- HVAC Has Zonal Electric Heating
- HVAC Heating Type
- Tenure.

Options

The options for the housing unit heating setpoint range between 55°F and 80°F (Table 99). All setpoints that are assigned 55°F are vacant units. The heating setpoint characteristic sets the `hvac_control_heating_season_period`, `hvac_control_heating_weekday_setpoint_temp`, `hvac_control_heating_weekend_setpoint_temp`, and `use_auto_heating_season` arguments. Argument definitions are in Table 100. The `hvac_control_heating_season_period` is always set to “auto,” and the `use_auto_heating_season` argument is always set to “false,” meaning the heating system will run as needed year-round. The heating set points are the same for weekdays and weekends.

Table 99. Heating Setpoint options and arguments that vary for each option

Option name	hvac_control_heating_weekday_setpoint_temp	hvac_control_heating_weekend_setpoint_temp
55F	55	55
60F	60	60
62F	62	62
65F	65	65
67F	67	67
68F	68	68
70F	70	70
72F	72	72
75F	75	75
76F	76	76
78F	78	78
80F	80	80

Table 100. The ResStock argument definitions set in the Heating Setpoint characteristic

Name	Required	Units	Type	Choices	Description
hvac_control_heating_season_period	false		String	auto	Enter a date like 'Nov 1 - Jun 30'. Can also provide 'BuildingAmerica' to use automatic seasons from the Building America House Simulation Protocols.
hvac_control_heating_weekday_setpoint_temp	true	deg-F	Double		Specify the weekday heating setpoint temperature.
hvac_control_heating_weekend_setpoint_temp	true	deg-F	Double		Specify the weekend heating setpoint temperature.
use_auto_heating_season	true		Boolean	true, false	Specifies whether to automatically define the heating season based on the weather file.

Distribution Assumption(s)

- For dependency conditions with low samples, the dependency values are lumped together in progressive order until there are enough samples: (1) lump buildings into Single-Family and Multifamily only, (2) lump buildings into Single-Family and Multifamily only, and lump nearby climate zones within A/B regions and separately 7AK and 8AK, and (3) lump all building types together, and lump climate zones within A/B regions and separately 7AK and 8AK.
- Heating type dependency is always lumped into Heat pump/Non-heat pumps.
- For vacant units (for which Tenure = ‘Not Available’), the heating setpoint is set to 55°F.

Heating Setpoint Has Offset

Description

Presence of a heating setpoint offset.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Building Type RECS
- HVAC Has Zonal Electric Heating.

Options

The options are either “Yes” or “No.” The options do not assign any ResStock arguments.

Distribution Assumption(s)

- For dependency conditions with low samples, the following dependency values are lumped together in progressive order until there are enough samples: (1) lump buildings into Single-Family and Multifamily only, and (2) lump all building types together.

Heating Setpoint Offset Magnitude

Description

The magnitude of the heating setpoint offset.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Building Type RECS
- Heating Setpoint Has Offset
- HVAC Has Zonal Electric Heating.

Options

The options for Heating Setpoint Offset Magnitude are 0F, 3F, 6F, and 12F (Table 101). The options are the °F that the heating setpoint is decreased if a heating setpoint offset is selected. The heating offset magnitude is the same for weekdays and weekends. The Heating Setpoint Offset Magnitude characteristic sets the `hvac_control_heating_weekday_setpoint_offset_magnitude` and `hvac_control_heating_weekend_setpoint_offset_magnitude` arguments. Argument definitions are in Table 102.

Table 101. Heating Setpoint Offset Magnitude options and arguments that vary for each option

Option name	`hvac_control_heating_weekday_setpoint_offset_magnitude`	`hvac_control_heating_weekend_setpoint_offset_magnitude`
0F	0	0
3F	3	3
6F	6	6
12F	12	12

Table 102. The ResStock argument definitions set in the Heating Setpoint Offset Magnitude characteristic

Name	Required	Units	Type	Choices	Description
`hvac_control_heating_weekday_setpoint_offset_magnitude`	true	deg-F	Double		Specify the weekday heating offset magnitude.
`hvac_control_heating_weekend_setpoint_offset_magnitude`	true	deg-F	Double		Specify the weekend heating offset magnitude.

Distribution Assumption(s)

- For dependency conditions with low samples, the following dependency values are lumped together in progressive order until there are enough samples: (1) lump buildings into Single-Family and Multifamily only, (2) lump buildings into Single-Family and Multifamily only, and lump nearby climate zones within A/B regions and separately 7AK and 8AK, and (3) lump all building types together and lump climate zones within A/B regions and separately 7AK and 8AK.

Heating Setpoint Offset Period

Description

The time period(s) for the housing unit's heating setpoint offset.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Building Type RECS
- Heating Setpoint Has Offset
- HVAC Has Zonal Electric Heating.

Options

The options are a combination of day and night offset periods (Table 103). The default for the day is from 9 AM to 5 PM and for the night is 10 PM to 7 AM. The options then shift these periods randomly up to 5 hours in either direction. The shifting of the periods is mainly to avoid the synchronization of HVAC systems across the housing stock from all turning on and off at the same time. The characteristic sets the `hvac_control_heating_weekday_setpoint_schedule` and `hvac_control_heating_weekend_setpoint_schedule` ResStock arguments. The values for the arguments are 24-hour arrays for when the setback occurs (a value of -1) and when the setback does not occur (a value of 0). The argument definitions are in Table 104.

Table 103. Heating Setpoint Offset Period options and arguments that vary for each option.

Option name	`hvac_control_heating_weekday_setpoint_schedule`	`hvac_control_heating_weekend_setpoint_schedule`

Table 103. Heating Setpoint Offset Period options and arguments that vary for each option. (continued)

Option name	`hvac_control_heating_weekday_setpoint_schedule`	`hvac_control_heating_weekend_setpoint_schedule`
Day	0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day -1h	0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day -2h	0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day -3h	0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day -4h	0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day -5h	0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day +1h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day +2h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day +3h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day +4h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day +5h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day and Night	-1, -1, -1, -1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, -1, -1	-1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1
Day and Night -1h	-1, -1, -1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, -1, -1, -1	-1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1
Day and Night -2h	-1, -1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, -1, -1, -1, -1	-1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1
Day and Night -3h	-1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1	-1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1
Day and Night -4h	-1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1	-1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1
Day and Night -5h	-1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1	-1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1
Day and Night +1h	-1, -1, -1, -1, -1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, -1	-1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1
Day and Night +2h	-1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0	-1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day and Night +3h	0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0	0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day and Night +4h	0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0	0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day and Night +5h	0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0	0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night	-1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1	-1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1
Night -1h	-1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1	-1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1
Night -2h	-1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1	-1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1

Table 103. Heating Setpoint Offset Period options and arguments that vary for each option. (continued)

Option name	`hvac_control_heating_weekday_setpoint_schedule`	`hvac_control_heating_weekend_setpoint_schedule`
Night -3h	-1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1	-1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1
Night -4h	-1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1	-1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1
Night -5h	-1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1	-1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1
Night +1h	-1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1	-1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1
Night +2h	-1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	-1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night +3h	0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night +4h	0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night +5h	0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
None	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

Table 104. The ResStock argument definitions set in the Heating Setpoint Offset Period characteristic

Name	Required	Units	Type	Choices	Description
`hvac_control_heating_weekday_setpoint_schedule`	true		String		Specify the 24-hour comma-separated weekday heating schedule of 0s and 1s.
`hvac_control_heating_weekend_setpoint_schedule`	true		String		Specify the 24-hour comma-separated weekend heating schedule of 0s and 1s.

Distribution Assumption(s)

- For dependency conditions with low samples, the following dependency values are lumped in progressive order until there are enough samples: (1) lump buildings into Single-Family and Multifamily only, (2) lump buildings into Single-Family and Multifamily only, and lump nearby climate zones within A/B regions and separately 7AK and 8AK, and (3) lump all building types together and lump climate zones within A/B regions and separately 7AK and 8AK.

Cooling Setpoint

Description

Baseline cooling setpoint (prior to any offset applied).

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Building Type RECS
- HVAC Cooling Type
- Tenure.

Options

The options for the Cooling Setpoint characteristic range between 60°F and 80°F (Table 105). The Cooling Setpoint characteristic sets the `hvac_control_cooling_season_period`, `hvac_control_cooling_weekday_setpoint_temp`, `hvac_control_cooling_weekend_setpoint_temp`, and `use_auto_cooling_season` ResStock arguments. The `hvac_control_cooling_season_period` argument is always set to “auto.” The `use_auto_cooling_season` argument is always set to “false.” These arguments allow the cooling system to run all year as needed. Argument definitions are in Table 106.

Table 105. Cooling Setpoint options and arguments that vary for each option

Option name	`hvac_control_cooling_weekday_setpoint_temp`	`hvac_control_cooling_weekend_setpoint_temp`
60F	60	60
62F	62	62
65F	65	65
67F	67	67
68F	68	68
70F	70	70
72F	72	72
75F	75	75
76F	76	76
78F	78	78
80F	80	80

Table 106. The ResStock argument definitions set in the Cooling Setpoint characteristic

Name	Required	Units	Type	Choices	Description
`hvac_control_cooling_season_period`	false		String	auto	Enter a date like 'Jun 1 - Oct 31'. Can also provide 'BuildingAmerica' to use automatic seasons from the Building America House Simulation Protocols.
`hvac_control_cooling_weekday_setpoint_temp`	true	deg-F	Double		Specify the weekday cooling setpoint temperature.
`hvac_control_cooling_weekend_setpoint_temp`	true	deg-F	Double		Specify the weekend cooling setpoint temperature.
`use_auto_cooling_season`	true		Boolean	true, false	Specifies whether to automatically define the cooling season based on the weather file.

Distribution Assumption(s)

- For dependency conditions with low samples, the following dependency values are lumped together in progressive order until there are enough samples: (1) lump buildings into Single-Family and Multifamily only, (2) lump buildings into Single-Family and Multifamily only, and lump nearby climate zones within A/B regions and separately 7AK and 8AK, (3) lump all building types together and lump climate zones within A/B regions and separately 7AK and 8AK, and (4) Owner and Renter are lumped together, which at this point only modifies AK distributions. Vacant units (for which Tenure = ‘Not Available’) are assumed to follow the same distribution as occupied units.

Cooling Setpoint Has Offset

Description
Presence of a cooling setpoint offset.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Building Type RECS.

Options
The options of the Cooling Setpoint Has Offset characteristic are “Yes” and “No.” An example of the offset for cooling is when the occupants leave the housing unit (e.g., commute to work), the cooling setpoint temperature is set up to a warmer temperature.

Distribution Assumption(s)

- For dependency conditions with low samples, the following dependency values are lumped in progressive order until there are enough samples: (1) lump buildings into Single-Family and Multifamily only, and (2) lump all building types together and lump climate zones within A/B regions and separately 7AK and 8AK.

Cooling Setpoint Offset Magnitude

Description
The magnitude of cooling setpoint offset.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Cooling Setpoint Has Offset
- Geometry Building Type RECS.

Options

The options of the Cooling Setpoint Offset Magnitude characteristic are 0°F, 2°F, 5°F, and 9°F (Table 108). The characteristic set the `hvac_control_cooling_weekday_setpoint_offset_magnitude` and `hvac_control_cooling_weekend_setpoint_offset_magnitude` ResStock arguments. A zero degree offset corresponds to the setpoint not having an offset. Argument definitions are in Table 107.

Table 107. The ResStock argument definitions set in the Cooling Setpoint Offset Magnitude characteristic

Name	Required	Units	Type	Choices	Description
`hvac_control_cooling_weekday_setpoint_offset_magnitude`	true	deg-F	Double		Specify the weekday cooling offset magnitude.
`hvac_control_cooling_weekend_setpoint_offset_magnitude`	true	deg-F	Double		Specify the weekend cooling offset magnitude.

Table 108. Cooling Setpoint Offset Magnitude options and arguments that vary for each option

Option name	`hvac_control_cooling_weekday_setpoint_offset_magnitude`	`hvac_control_cooling_weekend_setpoint_offset_magnitude`
0F	0	0
2F	2	2
5F	5	5
9F	9	9

Distribution Assumption(s)

- For dependency conditions with low samples, the following dependency values are lumped in progressive order until there are enough samples: (1) lump buildings into Single-Family and Multifamily only, (2) lump buildings into Single-Family and Multifamily only, and lump nearby climate zones within A/B regions and separately 7AK and 8AK, and (3) lump all building types together and lumping climate zones within A/B and separately 7AK and 8AK regions.

Cooling Setpoint Offset Period

Description

The time period(s) for the housing unit's heating setpoint offset.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Cooling Setpoint Has Offset
- Geometry Building Type RECS.

Options

The options combine day and night offset periods (Table 109). The default for the day is from 9 AM to 5 PM and for the night is 10 PM to 7 AM. The options then shift these periods randomly up to 5 hours in either direction. The shifting of the periods is mainly to avoid the synchronization of HVAC systems all turning on and off simultaneously. The characteristic set the `hvac_control_cooling_weekday_setpoint_schedule` and `hvac_control_cooling_weekdend_setpoint_schedule` ResStock arguments. The values for the arguments are hourly arrays for when the setup occurs (a value of 1), a setback (a value of -1), and when the setup or setback does not occur (a value of 0). The argument definitions are in Table 110.

Table 109. Cooling Setpoint Offset Period options and arguments that vary for each option

Option name	`hvac_control_cooling_weekday_setpoint_schedule`	`hvac_control_cooling_weekend_setpoint_schedule`
Day and Night Setup	1, 1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1,1, 1, 0, 0, 0, 0, 0, 1, 1	1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1
Day and Night Setup -1h	1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 1, 1, 1	1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1
Day and Night Setup -2h	1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 1, 1, 1, 1	1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1
Day and Night Setup -3h	1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1	1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1
Day and Night Setup -4h	1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1	1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1
Day and Night Setup -5h	1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1	1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1
Day and Night Setup +1h	1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 1	1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1
Day and Night Setup +2h	1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0	1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day and Night Setup +3h	0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0	0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day and Night Setup +4h	0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0	0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day and Night Setup +5h	0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0	0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup	0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup -1h	0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup -2h	0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup -3h	0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup -4h	0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup -5h	0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup +1h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup +2h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup +3h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

Table 109. Cooling Setpoint Offset Period options and arguments that vary for each option (continued)

Option name	`hvac_control_cooling_weekday_setpoint_schedule`	`hvac_control_cooling_weekend_setpoint_schedule`
Day Setup +4h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup +5h	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup and Night Setback	-1, -1, -1, -1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, -1, -1	-1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1
Day Setup and Night Setback -1h	-1, -1, -1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, -1, -1, -1	-1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1
Day Setup and Night Setback -2h	-1, -1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, -1, -1, -1, -1	-1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1
Day Setup and Night Setback -3h	-1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1	-1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1
Day Setup and Night Setback -4h	-1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1	-1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1
Day Setup and Night Setback -5h	-1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1	-1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1
Day Setup and Night Setback +1h	-1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, -1	-1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1
Day Setup and Night Setback +2h	-1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0	-1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup and Night Setback +3h	0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0	0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup and Night Setback +4h	0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0	0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Day Setup and Night Setback +5h	0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0	0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night Setback	-1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1	-1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1
Night Setback -1h	-1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1	-1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1
Night Setback -2h	-1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1	-1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1
Night Setback -3h	-1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1	-1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1
Night Setback -4h	-1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1	-1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1
Night Setback -5h	-1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1	-1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, -1, -1, -1, -1, -1, -1
Night Setback +1h	-1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1	-1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1
Night Setback +2h	-1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	-1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night Setback +3h	0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night Setback +4h	0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night Setback +5h	0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, -1, -1, -1, -1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night Setup	1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1	1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1

Table 109. Cooling Setpoint Offset Period options and arguments that vary for each option (continued)

Option name	`hvac_control_cooling_weekday_setpoint_schedule`	`hvac_control_cooling_weekend_setpoint_schedule`
Night Setup -1h	1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1	1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1
Night Setup -2h	1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1	1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1
Night Setup -3h	1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1	1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1
Night Setup -4h	1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1	1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1
Night Setup -5h	1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1	1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1
Night Setup +1h	1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1	1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1
Night Setup +2h	1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night Setup +3h	0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night Setup +4h	0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
Night Setup +5h	0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
None	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

Table 110. The ResStock argument definitions set in the Cooling Setpoint Offset Period characteristic

Name	Required	Units	Type	Choices	Description
`hvac_control_cooling_weekday_setpoint_schedule`	true		String		Specify the 24-hour comma-separated weekday cooling schedule of 0s and 1s.
`hvac_control_cooling_weekend_setpoint_schedule`	true		String		Specify the 24-hour comma-separated weekend cooling schedule of 0s and 1s.

Distribution Assumption(s)

- For dependency conditions with low samples, the following dependency values are lumped in progressive order until there are enough samples: (1) lump buildings into Single-Family and Multifamily only, (2) lump buildings into Single-Family and Multifamily only, and lump nearby climate zones within A/B regions and separately 7AK and 8AK, and (3) lump all building types together and lump climate zones within A/B and separately 7AK and 8AK regions.

8.4.6 Ducts

Modeling Approach

ResStock assigns three characteristics related to air distribution ductwork for each housing unit: whether there are ducts present, where the ducts are located, and a combined characteristic that includes the level of duct insulation and the amount of leakage from the ducts to unconditioned space. The location of the ductwork depends on the building type, the foundation type, the attic type, and presence of an attached garage, and if the housing unit has ducts. This is a direct map for each space combination. Air leakage and heat gains and losses are calculated for the fraction of the ductwork outside conditioned space. OpenStudio-HPXML assigns the fraction of the duct area in the conditioned space. Currently, in single-family homes, if the number of floors above grade is one, 100% of the duct surface area is outside the conditioned space. If the number of floors above grade is greater than one, then 75% of the duct surface area is outside the conditioned space. OpenStudio-HPXML also assigns fractions of supply/return ducts with a rectangular and circular cross-section, which affects the effective R-value for a given nominal duct insulation R-value.

ResStock has three inputs that control specify the primary ductwork arguments in the model:

- HVAC Has Ducts
- Duct Location
- Duct Leakage and Insulation.

HVAC Has Ducts

Description
The presence of ducts in the housing unit.

Distribution Data Source(s)

- The sample counts and sample weights are constructed using RECS 2020 microdata.

Direct Conditional Dependencies

- HVAC Cooling Type
- HVAC Has Shared System
- HVAC Heating Type
- HVAC Secondary Heating Type.

Options
Two options are available for this input characteristic: yes or no. The presence of ductwork is dependent upon the heating and cooling systems. Both duct options set the `hvac_blower_fan_watts_per_cfm` argument to auto.

For the argument definitions, see Table 111. See the OpenStudio-HPXML Air Distribution documentation for the available HPXML schema elements, default values, and constraints.

Table 111. The ResStock argument definitions set in the HVAC Has Ducts characteristic

Name	Required	Units	Type	Choices	Description
`hvac_blower_fan_watts_per_cfm`	false	W/CFM	Double	auto	The blower fan efficiency at maximum fan speed. Applies only to split (not packaged) systems (i.e., applies to ducted systems as well as ductless mini-split systems).

Distribution Assumption(s)

- Ducted Heat Pump HVAC type assumed to have ducts.
- Non-Ducted Heat Pump HVAC type assumed to have no ducts.
- There could be homes with non-ducted heat pump having ducts (Central AC with non-ducted heat pump), but due to structure of ResStock we are not accounting for those homes.
- None of the shared system options currently modeled (in HVAC Shared Efficiencies) are ducted, therefore where there are discrepancies between HVAC Heating Type, HVAC Cooling Type, and HVAC Has Shared System, HVAC Has Shared System takes precedence (e.g., Central AC + Ducted Heating + Shared Heating and Cooling = No (Ducts)). (This is a temporary fix and will change when ducted shared system options are introduced.)

Duct Leakage and Insulation

Description

Duct insulation and leakage to outside for the portion of ducts in unconditioned spaces.

Distribution Data Source(s)

- Duct insulation as a function of location: IECC 2009
- Leakage distribution: Lucas and Cole (2009). *Impacts of the 2009 IECC for Residential Buildings at State Level*.

Direct Conditional Dependencies

- Duct location
- Vintage.

Options

ResStock uses 13 combinations of insulation and air leakage from ducts (Table 112). The following ResStock arguments are constant across all options:

- `ducts_leakage_units`: percent
- `ducts_supply_buried_insulation_level`: auto
- `ducts_supply_fraction_rectangular`: auto
- `ducts_return_buried_insulation_level`: auto
- `ducts_return_fraction_rectangular`: auto.

Table 112. Duct Leakage and Insulation options and arguments that vary for each option

Option name	`ducts_supply_leakage_to_outside_value`	`ducts_supply_insulation_r`	`ducts_return_leakage_to_outside_value`	`ducts_return_insulation_r`
0% Leakage to Outside, Uninsulated	0	0	0	0
10% Leakage to Outside, R-4	0.067	4	0.033	4
10% Leakage to Outside, R-6	0.067	6	0.033	6
10% Leakage to Outside, R-8	0.067	8	0.033	8

Table 112. Duct Leakage and Insulation options and arguments that vary for each option (continued)

Option name	`ducts_supply_leakage_to_outside_value`	`ducts_supply_insulation_r`	`ducts_return_leakage_to_outside_value`	`ducts_return_insulation_r`
10% Leakage to Outside, Uninsulated	0.067	0	0.033	0
20% Leakage to Outside, R-4	0.133	4	0.067	4
20% Leakage to Outside, R-6	0.133	6	0.067	6
20% Leakage to Outside, R-8	0.133	8	0.067	8
20% Leakage to Outside, Uninsulated	0.133	0	0.067	0
30% Leakage to Outside, R-4	0.200	4	0.100	4
30% Leakage to Outside, R-6	0.200	6	0.100	6
30% Leakage to Outside, R-8	0.200	8	0.100	8
30% Leakage to Outside, Uninsulated	0.200	0	0.100	0
None	0	0	0	0

For the argument definitions, see Table 113. See the OpenStudio-HPXML Air Distribution documentation for the available HPXML schema elements, default values, and constraints.

Table 113. The ResStock argument definitions set in the Duct Leakage and Insulation characteristic

Name	Required	Units	Type	Choices	Description
`ducts_leakage_units`	true		Choice	CFM25, CFM50, Percent	The leakage units of the ducts.
`ducts_supply_leakage_to_outside_value`	true		Double		The leakage value to outside for the supply ducts.
`ducts_supply_insulation_r`	true	h-ft^2-R/Btu	Double		The nominal insulation r-value of the supply ducts excluding air films. Use 0 for uninsulated ducts.
`ducts_supply_buried_insulation_level`	false		Choice	auto, not buried, partially buried, fully buried, deeply buried	Whether the supply ducts are buried in, e.g., attic loose-fill insulation. Partially buried ducts have insulation that does not cover the top of the ducts. Fully buried ducts have insulation that just covers the top of the ducts. Deeply buried ducts have insulation that continues above the top of the ducts.
`ducts_supply_fraction_rectangular`	false	frac	Double	auto	The fraction of supply ducts that are rectangular (as opposed to round); this affects the duct effective R-value used for modeling.

Table 113. The ResStock argument definitions set in the Duct Leakage and Insulation characteristic (continued)

Name	Required	Units	Type	Choices	Description
`ducts_return_leakage_to_outside_value`	true		Double		The leakage value to outside for the return ducts.
`ducts_return_insulation_r`	true	h-ft^2-R/Btu	Double		The nominal insulation r-value of the return ducts excluding air films. Use 0 for uninsulated ducts.
`ducts_return_buried_insulation_level`	false		Choice	auto, not buried, partially buried, fully buried, deeply buried	Whether the return ducts are buried in, e.g., attic loose-fill insulation. Partially buried ducts have insulation that does not cover the top of the ducts. Fully buried ducts have insulation that just covers the top of the ducts. Deeply buried ducts have insulation that continues above the top of the ducts.
`ducts_return_fraction_rectangular`	false	frac	Double	auto	The fraction of return ducts that are rectangular (as opposed to round); this affects the duct effective R-value used for modeling.

Distribution Assumption(s)

Ducts entirely in conditioned spaces will not have any leakage to outside. Ducts with R-4/R-8 insulation were previously assigned to Geometry Foundation Type = Ambient or Slab. They now correspond to those with Duct Location = Garage, Unvented Attic, or Vented Attic.

Duct Location

Description

Primary location of duct system. As described earlier, a fraction of the ducts will also be assumed to be in conditioned space for homes with multiple stories.

Distribution Data Source(s)

- OpenStudio-HPXML v1.6.0 and Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014).

Direct Conditional Dependencies

- Geometry Space Combination
- HVAC Has Ducts.

Options

The duct location is a direct mapping of spaces from the hierarchical assignment in OpenStudio-HPXML. This is done to expose the duct location as an output in ResStock. The spaces available for the ducts are in Table 114. The “None” option is used for ducts that are located completely in the conditioned space. For all options of Duct Location, the following arguments are the same:

- `ducts_supply_surface_area`: auto

- `ducts_supply_surface_area_fraction`: auto
- `ducts_return_surface_area`: auto
- `ducts_return_surface_area_fraction`: auto.

Table 114. Duct Location options and arguments that vary for each option

Option name	`ducts_supply_location`	`ducts_return_location`	`ducts_number_of_return_registers`
Attic	attic	attic	auto
Crawlspace	crawlspace	crawlspace	auto
Garage	garage	garage	auto
Heated Basement	basement—conditioned	basement—conditioned	auto
Living Space	conditioned space	conditioned space	auto
Unheated Basement	basement—unconditioned	basement—unconditioned	auto
None	conditioned space	conditioned space	0

For the argument definitions, see Table 115. See the OpenStudio-HPXML Air Distribution documentation for the available HPXML schema elements, default values, and constraints.

Table 115. The ResStock argument definitions set in the Duct Location characteristic

Name	Required	Units	Type	Choices	Description
`ducts_supply_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, crawlspace, crawlspace—vented, crawlspace—unvented, crawlspace—conditioned, attic, attic—vented, attic—unvented, garage, exterior wall, under slab, roof deck, outside, other housing unit, other heated space, other multifamily buffer space, other non-freezing space, manufactured home belly	The location of the supply ducts.
`ducts_supply_surface_area`	false	ft^2	Double	auto	The supply ducts surface area in the given location.

Table 115. The ResStock argument definitions set in the Duct Location characteristic (continued)

Name	Required	Units	Type	Choices	Description
`ducts_supply_surface_area_fraction`	false	frac	Double	auto	The fraction of supply ducts surface area in the given location. Only used if Surface Area is not provided. If the fraction is less than 1, the remaining duct area is assumed to be in conditioned space.
`ducts_return_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, crawlspace, crawlspace—vented, crawlspace—unvented, crawlspace—conditioned, attic, attic—vented, attic—unvented, garage, exterior wall, under slab, roof deck, outside, other housing unit, other heated space, other multifamily buffer space, other non-freezing space, manufactured home belly	The location of the return ducts.
`ducts_return_surface_area`	false	ft^2	Double	auto	The return ducts surface area in the given location.
`ducts_return_surface_area_fraction`	false	frac	Double	auto	The fraction of return ducts surface area in the given location. Only used if Surface Area is not provided. If the fraction is less than 1, the remaining duct area is assumed to be in conditioned space.
`ducts_number_of_return_registers`	false	#	Integer	auto	The number of return registers of the ducts. Only used to calculate default return duct surface area.

Distribution Assumption(s)

Based on default duct location assignment in OpenStudio-HPXML: the first present space type in the order of: basement—conditioned, basement—unconditioned, crawlspace—conditioned, crawlspace—vented, crawlspace—unvented, attic—vented, attic—unvented, garage, or living space.

8.4.7 Unavailable HVAC Periods

Modeling Approach

Periods when the HVAC system is unavailable, either due to a system malfunction or because the household cannot afford to operate it, are modeled in ResStock. These periods are assigned using the availability schedules in OpenStudio-HPXML. Separate unavailability periods are defined for heating and cooling. The length of these periods can range from 0 days (indicating the HVAC system is always available) to a single day, or up to the entire year. If the "Year Round" option is sampled, the unavailability period is set to "Jan 1 - Dec 31." For a partial-year unavailability (e.g., 1, 7, 14 days, etc.), a randomly selected n-day period (where n is the duration of the unavailability) is chosen to start during the Building America heating or cooling months, as defined in the Building America House Simulation Protocols Wilson, Metzger, et al. 2014. In locations without Building America heating or cooling months (e.g., Hawaii has no heating months), the heating season is assumed to be December through February, and the cooling season is assumed to be June through August. If the number of unavailable days exceeds the length of the Building America season, the unavailability period extends beyond the defined season. To ensure deterministic simulations, the `building_id` is used as the seed for random date selection. There are two characteristics that sets the number of days the heating and cooling system is unavailable 1) Cooling Unavailable Days and 2) Heating Unavailable Days.

Cooling Unavailable Days

Description

Number of days in a year the cooling system is unavailable.

Distribution Data Source(s)

- U.S. EIA 2020 Residential Energy Consumption Survey (RECS) microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- Tenure

Options

The options of Cooling Unavailable Days characteristic are a number of days the cooling system is unavailable. The characteristic sets the `schedules_space_cooling_unavailable_days` argument. The argument definition can be found in Table 116.

Table 116. The ResStock argument definitions set in the Cooling Unavailable Days characteristic

Name	Required	Units	Type	Description
`schedules_space_cooling_unavailable_days`	false		Integer	Number of days space cooling equipment is unavailable.

The options range between 0 days (Never) to the whole year (year round). The Void option is for impossible combinations that are not sampled.

Table 117. Cooling Unavailable Days options and arguments that vary for each option

Option name	`schedules_space_cooling_unavailable_days`
Never	0
1 day	1
3 days	3
1 week	7
2 weeks	14
1 month	30
3 months	90
Year round	365
Void	

Distribution Assumption(s)

None

Heating Unavailable Days

Description

Number of days in a year the heating system is unavailable.

Distribution Data Source(s)

- U.S. EIA 2020 Residential Energy Consumption Survey (RECS) microdata.

Direct Conditional Dependencies

- Cooling Unavailable Days
- Federal Poverty Level
- Geometry Building Type RECS

Options

The options of Heating Unavailable Days characteristic are a number of days the cooling system is unavailable. The characteristic sets the `schedules_space_heating_unavailable_days` argument. The argument definition can be found in Table 118.

Table 118. The ResStock argument definitions set in the Heating Unavailable Days characteristic

Name	Required	Units	Type	Description
`schedules_space_heating_unavailable_days`	false		Integer	Number of days space heating equipment is unavailable.

The options range between 0 days (Never) to the whole year (year round). The Void option is for impossible combinations that are not sampled.

Table 119. Heating Unavailable Days options and arguments that vary for each option

Option name	`schedules_space_heating_unavailable_days`
Never	0
1 day	1
3 days	3
1 week	7

Table 119. Heating Unavailable Days options and arguments that vary for each option

Option name	`schedules_space_heating_unavailable_days`
2 weeks	14
1 month	30
3 months	90
Year round	365
Void	

Distribution Assumption(s)

- Where samples are less than 10, the data is aggregated in the following order until there are no rows with less than 10 samples:
  - The Federal Poverty Level dependency is aggregated every 100% bins
  - The Federal Poverty Level dependency is aggregated every 200% bins
  - The Geometry Building Type RECS dependency is aggregated into single-family, multi-family, and mobile home bins.
  - The Cooling Unavailable Days dependency is aggregated into days, weeks, month, and year round bins.
  - The Cooling Unavailable Days dependency is removed.

8.4.8 HVAC Installation Quality

Modeling Approach

ResStock includes features that allow users to account for the quality of HVAC installation. Two key factors that impact installation quality are the refrigeration charge and the airflow rate.

ResStock specifies the installed refrigerant charge as a percentage of the system's design charge for each option. It also sets the actual airflow rate per ton of cooling capacity, which may differ from the design airflow rate.

These variables, refrigerant charge fractions and airflow rates, can be adjusted for single-speed air conditioners and air-source heat pumps. However, despite these capabilities, ResStock currently does not make use of these options in the baseline model.

HVAC System Single-Speed ASHP Airflow

Description

Single-speed ASHP actual airflow rates for faulted systems. This input file is currently not used since ResStock is still lacking data on faults.

Distribution Data Source(s)

- *Impact of installation faults in air conditioners and heat pumps in single-family homes on U.S. energy usage* (Winkler et al. 2020).

Direct Conditional Dependencies

- HVAC Heating Efficiency
- HVAC System is Faulted.

Options

Thirteen options are available in ResStock, but currently none are used, and all homes as set to "None" (Table 120). The `cooling_system_rated_cfm_per_ton` for all 13 options is 400.0.

Table 120. HVAC System Single-Speed ASHP Airflow options and arguments that vary for each option

Option name	`cooling_system_actual_cfm_per_ton`
154.8 cfm/ton	154.8
204.4 cfm/ton	204.4
254.0 cfm/ton	254.0
303.5 cfm/ton	303.5
353.1 cfm/ton	353.1
402.7 cfm/ton	402.7
452.3 cfm/ton	452.3
501.9 cfm/ton	501.9
551.5 cfm/ton	551.5
601.0 cfm/ton	601.0
650.6 cfm/ton	650.6
700.2 cfm/ton	700.2
None	

For the argument definitions, see Table 121. See the OpenStudio-HPXML Air-to-Air Heat Pump documentation for the available HPXML schema elements, default values, and constraints.

Table 121. The ResStock argument definitions set in the HVAC System Single-Speed ASHP characteristic

Name	Required	Units	Type	Description
`cooling_system_rated_cfm_per_ton`	false	cfm/ton	Double	The rated cfm per ton of the cooling system.
`cooling_system_actual_cfm_per_ton`	false	cfm/ton	Double	The actual cfm per ton of the cooling system.

Distribution Assumption(s)

None

HVAC System Single-Speed ASHP Charge

Description

ASHP deviation between design/installed charge. Not currently used because of lack of data on faulted HVAC.

Distribution Data Source(s)

- *Impact of installation faults in air conditioners and heat pumps in single-family homes on U.S. energy usage* (Winkler et al. 2020).

Direct Conditional Dependencies

- HVAC Heating Efficiency
- HVAC System is Faulted.

Options

Seven different options are available for faulted ASHP charges, but none are currently in use (Table 122).

Table 122. HVAC System Single-Speed ASHP options and arguments that vary for each option

Option name	`heat_pump_frac_manufacturer_charge`
0.570 Charge Frac	0.570
0.709 Charge Frac	0.709

Table 122. HVAC System Single-Speed ASHP options and arguments that vary for each option

Option name	`heat_pump_frac_manufacturer_charge`
0.848 Charge Frac	0.848
0.988 Charge Frac	0.988
1.127 Charge Frac	1.127
1.266 Charge Frac	1.266
1.405 Charge Frac	1.405
None	

For the argument definitions, see Table 123. See the OpenStudio-HPXML Air-to-Air Heat Pumps documentation for the available HPXML schema elements, default values, and constraints.

Table 123. The ResStock argument definitions set in the HVAC Secondary Heating characteristic

Name	Required	Units	Type	Description
`heat_pump_frac_manufacturer_charge`	false	Frac	Double	The fraction of manufacturer recommended charge of the heat pump.

HVAC System Single-Speed AC Airflow

Description

Single-speed central and room air conditioner actual air flow rates for faulted systems. Not currently used since ResStock lacks data on faulted systems.

Distribution Data Source(s)

- *Impact of installation faults in air conditioners and heat pumps in single-family homes on U.S. energy usage* (Winkler et al. 2020).

Direct Conditional Dependencies

- HVAC Cooling Efficiency
- HVAC System is Faulted.

Options

Twelve options are given for real airflow, but none are currently in use (Table 124). The `heat_pump_rated_cfm_per_ton` argument is set to 400 for all options.

Table 124. HVAC System Single-Speed AC Airflow options and arguments that vary for each option

Option name	`heat_pump_actual_cfm_per_ton`
154.8 cfm/ton	154.8
204.4 cfm/ton	204.4
254.0 cfm/ton	254.0
303.5 cfm/ton	303.5
353.1 cfm/ton	353.1
402.7 cfm/ton	402.7
452.3 cfm/ton	452.3
501.9 cfm/ton	501.9
551.5 cfm/ton	551.5
601.0 cfm/ton	601.0
650.6 cfm/ton	650.6

Table 124. HVAC System Single-Speed AC Airflow options and arguments that vary for each option

Option name	`heat_pump_actual_cfm_per_ton`
700.2 cfm/ton	700.2
None	100%

For the argument definitions, see Table 125. See the OpenStudio-HPXML Central Air Conditioner documentation for the available HPXML schema elements, default values, and constraints.

Table 125. The ResStock argument definitions set in the HVAC System Single-Speed AC Airflow characteristic

Name	Required	Units	Type s	Description
`heat_pump_rated_cfm_per_ton`	false	cfm/ton	Double	The rated cfm per ton of the heat pump.
`heat_pump_actual_cfm_per_ton`	false	cfm/ton	Double	The actual cfm per ton of the heat pump.

Distribution Assumption(s)

None

HVAC System Single-Speed AC Charge

Description

Central and room air conditioner deviation between design/installed charge.

Distribution Data Source(s)

- *Impact of installation faults in air conditioners and heat pumps in single-family homes on U.S. energy usage* (Winkler et al. 2020).

Direct Conditional Dependencies

- HVAC Cooling Efficiency
- HVAC System is Faulted.

Options

Seven different options are available for faulted AC charges, but none are currently in use (Table 126).

Table 126. HVAC System Single-Speed AC Charge options and arguments that vary for each option

Option name	`cooling_system_frac_manufacturer_charge`
0.570 Charge Frac	0.570
0.709 Charge Frac	0.709
0.848 Charge Frac	0.848
0.988 Charge Frac	0.988
1.127 Charge Frac	1.127
1.266 Charge Frac	1.266
1.405 Charge Frac	1.405
None	

For the argument definitions, see Table 127. See the OpenStudio-HPXML Air Distribution documentation for the available HPXML schema elements, default values, and constraints.

Table 127. The ResStock argument definitions set in the HVAC System Single-Speed AC Charge

Name	Required	Units	Type	Description
`cooling_system_frac_manufacturer_charge`	false	Frac	Double	The fraction of manufacturer recommended charge of the cooling system.

Distribution Assumption(s)

None.

Distribution Assumption(s)

None.

HVAC System is Scaled

Description

Whether the HVAC system has been undersized or oversized (not used in baseline) compared to what was autosized using ACCA Manual J and Manual S.

Distribution Data Source(s)

This is currently a capability that is not used. ResStock assumes no oversizing or undersizing, until we have the data necessary to characterize all types of systems.

Direct Conditional Dependencies

None.

Options

All buildings assigned an option of “No” with no associated ResStock arguments.

Distribution Assumption(s)

None.

HVAC System is Faulted

Description

The presence of an HVAC system giving a fault or error. Note: this is a capability but is not used in baseline ResStock.

Distribution Data Source(s)

N/A.

Direct Conditional Dependencies

None.

Options

All homes currently set to “No” with no associated ResStock arguments.

Distribution Assumption(s)

None.

8.4.9 Ventilation

Modeling Approach

Mechanical ventilation, natural ventilation, and local ventilation fans (bath fan, range fan) can be modeled in ResStock. There is currently no mechanical ventilation in the baseline. The bath fan and range fan operate for one hour a day according to the daily hourly schedule specified in the Bathroom Spot Vent Hour and Range Spot Vent Hour characteristics. In aggregate, the distributions of the Bathroom Spot Vent Hour and Range Spot Vent Hour characteristics provide an average schedule for a group of housing units. For default, constraints, and notes about the modeling approach see OpenStudio-HPXML Local Ventilation Fans documentation. Natural ventilation (through opening the windows) is allowed during the Cooling Season under certain outside conditions set by the 2010 House Simulation Protocols (Hendron and Engebrecht 2010). When ventilating, 1/3 of the operable windows are open for natural ventilation (Hendron and Engebrecht 2010).

Four different input files influence ventilation in ResStock:

- Mechanical Ventilation
- Natural Ventilation
- Bathroom Spot Vent Hour
- Range Spot Vent Hour.

Mechanical ventilation is currently not used in the baseline, and natural ventilation has a single option assigned to all homes. Bathroom Spot Vent Hour and Range Spot Vent Hour provide diversity in the schedules of operation of localized bathroom and cooking ventilation, respectively.

Mechanical Ventilation

Description
Mechanical ventilation type and efficiency.

Distribution Data Source(s)
Engineering judgment.

Direct Conditional Dependencies
None.

Options
In the baseline, no homes are assigned mechanical ventilation, so only the option “None” is used and all arguments are set to None or 0:

- `mech_vent_fan_type`: none
- `mech_vent_flow_rate`: 0
- `mech_vent_hours_in_operation`: 0
- `mech_vent_recovery_efficiency_type`: unadjusted
- `mech_vent_total_recovery_efficiency`: 0
- `mech_vent_sensible_recovery_efficiency`: 0
- `mech_vent_fan_power`: 0
- `mech_vent_num_units_served`: 0
- `mech_vent_shared_frac_recirculation`: auto
- `mech_vent_shared_preheating_fuel`: auto
- `mech_vent_shared_preheating_efficiency`: auto

- `mech_vent_shared_preheating_fraction_heat_load_served`: auto
- `mech_vent_shared_precooling_fuel`: auto
- `mech_vent_shared_precooling_efficiency`: auto
- `mech_vent_shared_precooling_fraction_cool_load_served`: auto
- `mech_vent_2_fan_type` : none
- `mech_vent_2_flow_rate`: 0
- `mech_vent_2_hours_in_operation`: 0
- `mech_vent_2_recovery_efficiency_type`: unadjusted
- `mech_vent_2_total_recovery_efficiency`: 0
- `mech_vent_2_sensible_recovery_efficiency`: 0
- `mech_vent_2_fan_power`: 0
- `whole_house_fan_present`: false
- `whole_house_fan_flow_rate`: 0
- `whole_house_fan_power`: 0.

For the argument definitions, see Table 128. See the OpenStudio-HPXML Mechanical Ventilation Fans and Local Ventilation Fans documentation for the available HPXML schema elements, default values, and constraints.

Table 128. The ResStock argument definitions set in the Mechanical Ventilation characteristic

Name	Required	Units	Type	Choices	Description
`mech_vent_fan_type`	true		Choice	none, exhaust only, supply only, energy recovery ventilator, heat recovery ventilator, balanced, central fan integrated supply	The type of the mechanical ventilation. Use 'none' if there is no mechanical ventilation system.
`mech_vent_flow_rate`	false	CFM	Double	auto	The flow rate of the mechanical ventilation.
`mech_vent_hours_in_operation`	false	hrs/day	Double	auto	The hours in operation of the mechanical ventilation.
`mech_vent_recovery_efficiency_type`	true		Choice	Unadjusted, Adjusted	The total recovery efficiency type of the mechanical ventilation.
`mech_vent_total_recovery_efficiency`	true	Frac	Double		The Unadjusted or Adjusted total recovery efficiency of the mechanical ventilation. Applies to energy recovery ventilator.

Table 128. The ResStock argument definitions set in the Mechanical Ventilation characteristic (continued)

Name	Required	Units	Type	Choices	Description
`mech_vent_sensible_recovery_efficiency`	true	Frac	Double		The Unadjusted or Adjusted sensible recovery efficiency of the mechanical ventilation. Applies to energy recovery ventilator and heat recovery ventilator.
`mech_vent_fan_power`	false	W	Double	auto	The fan power of the mechanical ventilation.
`mech_vent_num_units_served`	true	#	Integer		Number of housing units served by the mechanical ventilation system. Must be 1 if single-family detached. Used to apportion flow rate and fan power to the unit.
`mech_vent_shared_frac_recirculation`	false	Frac	Double		Fraction of the total supply air that is recirculated, with the remainder assumed to be outdoor air. The value must be 0 for exhaust only systems. Required for a shared mechanical ventilation system.
`mech_vent_shared_preheating_fuel`	false		Choice	auto, electricity, natural gas, fuel oil, propane, wood, wood pellets, coal	Fuel type of the pre-conditioning heating equipment. Only used for a shared mechanical ventilation system. If not provided, assumes no preheating.
`mech_vent_shared_preheating_efficiency`	false	COP	Double		Efficiency of the pre-conditioning heating equipment. Only used for a shared mechanical ventilation system. If not provided, assumes no preheating.
`mech_vent_shared_preheating_fraction_heat_load_served`	false	Frac	Double		Fraction of heating load introduced by the shared ventilation system that is met by the preconditioning heating equipment. If not provided, assumes no preheating.

Table 128. The ResStock argument definitions set in the Mechanical Ventilation characteristic (continued)

Name	Required	Units	Type	Choices	Description
`mech_vent_shared_precooling_fuel`	false		Choice	auto, electricity	Fuel type of the preconditioning cooling equipment. Only used for a shared mechanical ventilation system. If not provided, assumes no precooling.
`mech_vent_shared_precooling_efficiency`	false	COP	Double		Efficiency of the preconditioning cooling equipment. Only used for a shared mechanical ventilation system. If not provided, assumes no precooling.
`mech_vent_shared_precooling_fraction_cool_load_served`	false	Frac	Double		Fraction of cooling load introduced by the shared ventilation system that is met by the preconditioning cooling equipment. If not provided, assumes no precooling.
`mech_vent_2_fan_type`	true		Choice	none, exhaust only, supply only, energy recovery ventilator, heat recovery ventilator, balanced	The type of the second mechanical ventilation. Use 'none' if there is no second mechanical ventilation system.
`mech_vent_2_flow_rate`	true	CFM	Double		The flow rate of the second mechanical ventilation.
`mech_vent_2_hours_in_operation`	true	hrs/day	Double		The hours in operation of the second mechanical ventilation.
`mech_vent_2_recovery_efficiency_type`	true		Choice	Unadjusted, Adjusted	The total recovery efficiency type of the second mechanical ventilation.
`mech_vent_2_total_recovery_efficiency`	true	Frac	Double		The Unadjusted or Adjusted total recovery efficiency of the second mechanical ventilation. Applies to energy recovery ventilator.
`mech_vent_2_sensible_recovery_efficiency`	true	Frac	Double		The Unadjusted or Adjusted sensible recovery efficiency of the second mechanical ventilation. Applies to energy recovery ventilator and heat recovery ventilator.

Table 128. The ResStock argument definitions set in the Mechanical Ventilation characteristic (continued)

Name	Required	Units	Type	Choices	Description
`mech_vent_2_fan_power`	true	W	Double		The fan power of the second mechanical ventilation.
`whole_house_fan_present`	true		Boolean	true, false	Whether there is a whole house fan.
`whole_house_fan_flow_rate`	false	CFM	Double	auto	The flow rate of the whole house fan.

Distribution Assumption(s)

None.

Natural Ventilation

Description

Amount and schedule of natural ventilation through operable windows.

Distribution Data Source(s)

Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014).

Direct Conditional Dependencies

None.

Options

All homes are currently set to the same natural ventilation option.

Table 129. Natural Ventilation options and arguments that vary for each option

Option name	`window_fraction_operable`
Cooling Season, 7 days/wk	0.67

For the argument definitions, see Table 130. See the OpenStudio-HPXML Natural Ventilation documentation for the available HPXML schema elements, default values, and constraints.

Table 130. The ResStock argument definitions set in the Natural Ventilation characteristic

Name	Required	Units	Type	Choices	Description
`window_fraction_operable`	false	Frac	Double	auto	Fraction of windows that are operable.

Distribution Assumption(s)

None.

Bathroom Spot Vent Hour

Description

Bathroom spot ventilation daily start hour. In ResStock, the bathroom fan(s) operates for 1 hour everyday. A schedule is generated on the fly based on these inputs.

Distribution Data Source(s)

Same as occupancy schedule from the Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014).

Direct Conditional Dependencies

None.

Options

The start hours are spread out over all 24 hours of the day (Table 131). The following ResStock arguments are constant across all options:

- `bathroom_fans_quantity`: auto
- `bathroom_fans_flow_rate`: auto
- `bathroom_fans_hours_in_operation`: auto
- `bathroom_fans_power`: auto.

Table 131. Bathroom Spot Vent Hour options and arguments that vary for each option

Option name	`bathroom_fans_start_hour`
Hour0	0
Hour1	1
Hour2	2
Hour3	3
Hour4	4
Hour5	5
Hour6	6
Hour7	7
Hour8	8
Hour9	9
Hour10	10
Hour11	11
Hour12	12
Hour13	13
Hour14	14
Hour15	15
Hour16	16
Hour17	17
Hour18	18
Hour19	19
Hour20	20
Hour21	21
Hour22	22
Hour23	23

For the argument definitions, see Table 132. See the OpenStudio-HPXML Local Ventilation Fans documentation for the available HPXML schema elements, default values, and constraints.

Table 132. The ResStock argument definitions set in the Bathroom Spot Vent Hour characteristic

Name	Required	Units	Type	Choices	Description
`bathroom_fans_quantity`	false	#	Integer	auto	The quantity of the bathroom fans.

Table 132. The ResStock argument definitions set in the Bathroom Spot Vent Hour characteristic

Name	Required	Units	Type	Choices	Description
`bathroom_fans_flow_rate`	false	CFM	Double	auto	The flow rate of the bathroom fans.
`bathroom_fans_hours_in_operation`	false	hrs/day	Double	auto	The hours in operation of the bathroom fans.
`bathroom_fans_power`	false	W	Double	auto	The fan power of the bathroom fans.
`bathroom_fans_start_hour`	false	hr	Integer	auto	The start hour of the bathroom fans.

Distribution Assumption(s)

None.

Range Spot Vent Hour

Description

Range spot ventilation daily start hour. In ResStock, the range hood operates for 1 hour every day. A schedule is generated on the fly for range spot ventilation based on these inputs.

Distribution Data Source(s)

Derived from national average cooking range schedule in Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014).

Direct Conditional Dependencies

None.

Options

Start hours are spread across all hours of the day (Table 133). Across the options the following ResStock arguments are constant:

- `kitchen_fans_quantity`: auto
- `kitchen_fans_flow_rate`: auto
- `kitchen_fans_hours_in_operation`: auto
- `kitchen_fans_power`: auto.

Table 133. Range Spot Vent Hour options and arguments that vary for each option

Option name	`kitchen_fans_start_hour`
Hour0	0
Hour1	1
Hour2	2
Hour3	3
Hour4	4
Hour5	5
Hour6	6
Hour7	7
Hour8	8
Hour9	9
Hour10	10
Hour11	11

Table 133. Range Spot Vent Hour options and arguments that vary for each option

Option name	`kitchen_fans_start_hour`
Hour12	12
Hour13	13
Hour14	14
Hour15	15
Hour16	16
Hour17	17
Hour18	18
Hour19	19
Hour20	20
Hour21	21
Hour22	22
Hour23	23

For the argument definitions, see Table 134. See the OpenStudio-HPXML Local Ventilation documentation for the available HPXML schema elements, default values, and constraints.

Table 134. The ResStock argument definitions set in the Range Spot Vent Hour characteristic

Name	Required	Units	Type	Choices	Description
`kitchen_fans_quantity`	false	#	Integer	auto	The quantity of the kitchen fans.
`kitchen_fans_flow_rate`	false	CFM	Double	auto	The flow rate of the kitchen fan.
`kitchen_fans_hours_in_operation`	false	hrs/day	Double	auto	Hours per day of operation.
`kitchen_fans_power`	false	W	Double	auto	The fan power of the kitchen fan.
`kitchen_fans_start_hour`	false	hr	Integer	auto	The start hour of the kitchen fan.

Distribution Assumption(s)

None.

8.5 Water Heating

Water heating describes the system that provides domestic hot water and distributes it for use at the fixtures or by appliances, such as dishwashers and clothes washers. This section covers water heaters, hot water distribution, and hot water use for fixtures and appliances. For building characterization, ResStock provides distributions for how many housing units have a standalone water heater vs. a shared central water heater (Water Heater In Unit: Section 8.5.1), where the water heater is located (Water Heater Location: Section 8.5.1), water heating fuel (Water Heater Fuel: Section 8.5.1), and water heater specification (Water Heater Efficiency: Section 8.5.1). Additionally, ResStock characterizes the piping material and insulation level for distributing hot water to the fixtures (Hot Water Distribution: Section 8.5.2), as well as the fixture usage and flow levels in the form of usage multipliers (Hot Water Fixtures: Section 8.5.3).

8.5.1 Water Heaters

Modeling Approach

A water heater can be a standalone in-unit appliance or a centrally located system that serves multiple units in a multifamily or single-family attached building. ResStock models different water heating technologies, heating fuels, installation locations, and storage options. ResStock defines the heating efficiency and location using probability distributions. ResStock relies on OpenStudio-HPXML default assumptions for other technical details. To this end, all water heaters are modeled with a setpoint of 125°F. All fuel water heaters with an energy factor less than 0.63 are assumed to have an open flue, which increases the housing unit's air infiltration for water heaters located in conditioned space.

Tank Water Heaters

Conventional storage water heaters are modeled as mixed tanks without additional tank insulation. ResStock calculates the amount of tank losses and the burner efficiency using an energy factor and recovery efficiency (Maguire and Roberts 2020). The recovery efficiency is 0.98 for electric tanks by fiat. The tank volume and heating capacity are calculated based on the number of bedrooms and bathrooms, per Table 8 of the 2014 House Simulation Protocol (which is based upon guidance from the U.S. Department of Housing and Urban Development [HUD]).

Tankless Water Heaters

Tankless water heaters, unlike storage water heaters, are designed to produce hot water on demand. To this end, they are typically equipped with a burner or electric elements several times larger in capacity. They are also much more compact. In ResStock, their heating performance is defined using an energy factor, which is further derated by 8% to account for cycling (International Code Council 2019).

Heat Pump Water Heaters

Heat pump water heaters are storage water heaters that use a refrigerant cycle to extract heat from the surrounding air to produce hot water. Heat pump water heaters are modeled with a stratified tank model, rather than a mixed tank like conventional storage water heaters. ResStock defines their heating performance using a uniform energy factor and first hour rating. The tank volume is defined by a housing characteristic distribution. Heat pump water heaters are modeled to operate in a hybrid mode, meaning the electric resistance backup only turns on to supplement the heat pump.

Solar Thermal Water Heaters

A solar hot water heater is a system that uses the sun to heat water. Typically it has a rooftop collector to absorb solar energy, and water or antifreeze is circulated through the collector to a tank with a heat exchanger. The solar thermal model takes inputs that define the collector characteristics, such as system type, collector area, solar loop type, orientation, tilt, rated optical efficiency and thermal losses, and storage volume (for integrated collector storage units). In ResStock, all solar water heaters are integrated collector units with a secondary backup storage tank, i.e., two-tank systems. To model a typical solar water heater with a single tank that has backup heating elements, the secondary tank is given a R-6.2 jacket to reduce the standby loss of the secondary tank.

Other Water Heaters

ResStock does not model building-level shared water heaters. Instead, ResStock models shared water heaters as equivalent in-unit style water heaters located in a heated common space outside the unit. This is due to ResStock's current approach of modeling multifamily as singular housing units rather than as buildings consisting of multiple units, which limits the modeling of any shared systems. The out-of-unit location ensures that these water heaters do not generate tank losses that a housing unit's HVAC system must address. However, this proxy modeling approach does not account for the differences in piping and tank losses from central water heaters. In addition to systems shared by multiple units, ResStock does not model combination systems that provide other services such as space conditioning in addition to hot water.

Water Heater Fuel

Description

The water heater fuel type.

Distribution Data Sources

- U.S. EIA 2020 RECS microdata

- Alaska-specific distribution is based on Alaska Retrofit Information System (2008 to 2022), maintained by Alaska Housing Finance Corporation.

Direct Conditional Dependencies

- Geometry Building Type RECS
- Heating Fuel
- State

Options

Water Heater Fuel has options of Electricity, Fuel Oil, Natural Gas, Solar Thermal, Wood, and Other Fuel. The characteristic does not set any ResStock arguments. Instead, it is a direct dependency for Water Heater Efficiency, where the heating fuel is assigned individually for each water heater option. Through this dependency, any changes to the distribution of water heater fuels will cascade to influence the water heater types. After conversations with EIA the Other Fuel water heater is typically composed of respondents saying they either do not have a water heater, coal, biomass, or district steam systems. ResStock models the energy associated with Other Fuel water heaters as coal energy consumption.

Distribution Assumptions

- Due to low sample sizes, fallback rules are applied, with lumping of:
  - State: Census Division RECS
  - Geometry building SF: Mobile, Single-family attached, Single-family detached
  - Geometry building MF: Multifamily with 2–4 Units, Multifamily with 5+ Units
  - State: Census Region
  - State: National
- For Alaska, we are using a field in ARIS that lumps multifamily 2–4 units and multifamily 5+ units buildings together. Data from the American Community Survey are used to distribute between these two building types.
- For Alaska, wood and coal heating is modeled as other fuel.
- For Alaska, when a building uses more than one fuel for water heating, the fuel with highest consumption is considered the water heater fuel and used to meet all loads.

Water Heater In Unit

Description

Presence of an individual water heater in the housing unit that solely serves the specific housing unit.

Distribution Data Sources

- U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Geometry Building Type RECS
- State
- Vintage ACS

Options

In the ResStock baseline, all housing units have access to hot water and use energy for water heating. This characteristic has no ResStock arguments. Instead, it is used to separate water heating energy between in-unit versus shared designations. As a direct dependency to Water Heater Location, it ensures water heaters not in-unit are located appropriately and have no interaction with in-unit end-use loads.

Distribution Assumptions

- All water heaters for Single-Family Detached and Mobile Homes are in-unit (not shared).
- Single-Family Attached assumes the distribution from RECS 2009 because RECS 2020 does not have this breakdown.
- Due to low sample sizes, fallback rules are applied, with lumping of:
  - State: Census Division RECS
  - Vintage ACS: Combining Vintage pre-1960s and post-2000
  - State: Census Region.

Water Heater Location

Description

Location of the water heater.

Distribution Data Sources

- U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- ASHRAE IECC Climate Zone 2004
- Geometry Space Combination
- Vintage ACS
- Water Heater In Unit.

Options

The options are spaces where the water heater can be located (Table 135). The Conditioned Mechanical Room option is only used for multifamily units with shared water heating. This option assigns the `water_heater_location` ResStock argument.

Table 135. Water Heater Location options and arguments that vary for each option

Option name	`water_heater_location`
Attic	attic
Conditioned Mechanical Room	other heated space
Crawlspace	crawlspace
Garage	garage
Heated Basement	basement—conditioned
Living Space	conditioned space
Outside	other exterior
Unheated Basement	basement—unconditioned

For the argument definitions, see Table 136. See the OpenStudio-HPXML Water Heating Systems documentation for the available HPXML schema elements, default values, and constraints.

Table 136. The ResStock argument definitions set in the Water Heater Location characteristic

Name	Required	Units	Type	Choices	Description
`water_heater_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, garage, attic, attic—vented, attic—unvented, crawlspace, crawlspace—vented, crawlspace—unvented, crawlspace—conditioned, other exterior, other housing unit, other heated space, other multifamily buffer space, other non-freezing space	The location of water heater.

Distribution Assumptions

- H2OMAIN = other is equally distributed among attic and crawlspace.
- H2OMAIN does not apply to multifamily, therefore Water heater location for multifamily with in-unit water heater is taken after the combined distribution of other building types.
- Out-of-unit water heater is assumed to be in Conditioned Mechanical Room. Per expert judgment, water heaters cannot be outside or in vented spaces for IECC Climate Zones 4-8 due to pipe-freezing risk.
- Where samples < 10, data are aggregated in the following order:
  - Building Type lumped into single-family, multifamily, and mobile home.
  - 1 + Foundation Type combined.
  - 2 + Attic Type combined
  - 3 + Garage combined.
  - Single/Multifamily + Foundation combined + Attic combined + Garage combined.
  - 5 + pre-1960 combined.
  - 5 + pre-1960 combined/post-2020 combined.
  - 7 + IECC Climate Zone lumped into: 1-2+3A, 3B-3C, 4, 5, 6, 7 except AK, 7AK-8AK.
  - 7 + IECC Climate Zone lumped into: 1-2-3, 4-8.

Water Heater Efficiency

Description

The efficiency and type of the water heater by heating fuel.

Distribution Sources

- U.S. EIA 2020 RECS microdata.
- Heat pump water heaters: 2016-17 RBSA II for WA and OR; Butzbaugh et al. (2017). *US HPWH Market Transformation: Where We've Been and Where to Go Next* for remainder of regions.
- Penetration of HPWH for Maine (6.71%) calculated based on total number of HPWH units (from AWHI Stakeholder Meeting 12/08/2022) and total housing units (from https://www.census.gov/quickfacts/ME).

Direct Conditional Dependencies

- State
- Water Heater Fuel

Options

Water Heater Efficiency options define the technical details of the standalone water heaters and solar thermal water heaters with storage backup, from fuel type to the presence of flue (Table 137). The following arguments are constant across the non-solar standalone water heater options. The arguments for solar water heater options are available further down.

- `water_heater_backup_heating_capacity`: auto
- `water_heater_has_flue_or_chimney`: auto
- `water_heater_heating_capacity`: auto
- `water_heater_num_bedrooms_served`: auto
- `water_heater_operating_mode`: auto
- `water_heater_setpoint_temperature`: 125
- `water_heater_standby_loss`: 0
- `water_heater_jacket_rvalue`: 0
- `water_heater_tank_model_type`: auto
- `water_heater_usage_bin`: auto
- `water_heater_uses_desuperheater`: auto
- `solar_thermal_system_type`: none
- `solar_thermal_collector_area`: 40
- `solar_thermal_collector_loop_type`: liquid indirect
- `solar_thermal_collector_type`: single glazing black
- `solar_thermal_collector_azimuth`: 0
- `solar_thermal_collector_tilt`: 0
- `solar_thermal_collector_rated_optical_efficiency`: 0.77
- `solar_thermal_collector_rated_thermal_losses`: 0.793
- `solar_thermal_storage_volume`: auto
- `solar_thermal_solar_fraction`: 0

For heat pump water heaters the `water_heater_efficiency_type` UniformEnergyFactor is used; EnergyFactor is currently used for all other water heaters.

Table 137. Water Heater Efficiency options and arguments that vary for each option of storage and tankless water heaters.

Option name	`water_heater_type`	`water_heater_fuel_type`	`water_heater_tank_volume`	`water_heater_efficiency_type`	`water_heater_recovery_efficiency`
Electric Heat Pump, 50 gal, 3.45 UEF	heat pump water heater	electricity	50	3.45	0

Table 137. Water Heater Efficiency options and arguments that vary for each option of storage and tankless water heaters. (continued)

Option name	`water_heater_type`	`water_heater_fuel_type`	`water_heater_tank_volume`	`water_heater_efficiency_type`	`water_heater_recovery_efficiency`
Electric Heat Pump, 66 gal, 3.35 UEF	heat pump water heater	electricity	66	3.35	0
Electric Heat Pump, 80 gal, 3.45 UEF	heat pump water heater	electricity	80	3.45	0
Electric Premium	storage water heater	electricity	auto	0.95	0
Electric Standard	storage water heater	electricity	auto	0.92	0
Electric Tankless	instantaneous water heater	electricity	0	0.99	0
FIXME Fuel Oil Indirect	storage water heater	fuel oil	auto	0.62	0.78
Fuel Oil Premium	storage water heater	fuel oil	auto	0.68	0.9
Fuel Oil Standard	storage water heater	fuel oil	auto	0.62	0.78
Natural Gas Premium	storage water heater	natural gas	auto	0.67	0.78
Natural Gas Standard	storage water heater	natural gas	auto	0.59	0.76
Natural Gas Tankless	instantaneous water heater	natural gas	0	0.82	0
Other Fuel	storage water heater	coal	auto	0.59	0.76
Propane Premium	storage water heater	propane	auto	0.67	0.78
Propane Standard	storage water heater	propane	auto	0.59	0.76
Propane Tankless	instantaneous water heater	propane	0	0.82	0
Wood	storage water heater	wood	auto	0.59	0.76

Solar thermal water heaters are characterized by `solar_thermal_system_type=hot water`. The following arguments are constant across the solar water heater options:

- `water_heater_type`: storage water heater
- `water_heater_backup_heating_capacity`: auto
- `water_heater_has_flue_or_chimney`: auto
- `water_heater_heating_capacity`: auto
- `water_heater_num_bedrooms_served`: auto
- `water_heater_operating_mode`: auto
- `water_heater_setpoint_temperature`: 125
- `water_heater_standby_loss`: 0

- `water_heater_tank_model_type`: auto
- `water_heater_tank_volume`: auto
- `water_heater_usage_bin`: auto
- `water_heater_uses_desuperheater`: auto
- `solar_thermal_system_type`: hot water
- `solar_thermal_collector_area`: 40
- `solar_thermal_collector_loop_type`: liquid indirect
- `solar_thermal_collector_type`: single glazing black
- `solar_thermal_collector_rated_optical_efficiency`: 0.77
- `solar_thermal_collector_rated_thermal_losses`: 0.793
- `solar_thermal_storage_volume`: auto
- `solar_thermal_solar_fraction`: 0

The options for solar water heaters in ResStock distinguishes by orientation and backup fuel as shown in Table 138. The tilt of the collector is set to roof pitch for all options. The azimuth of the collector varies by option, with East (90°), South (180°), West (270°), and North (0°) orientations available. All solar water heaters are modeled as two-tank systems, where the backup has its own storage separately from the primary tank. While this may be the common configuration for fuel backup systems, it is less common for electric backup systems, which often use a single tank with integrated solar and electric heating elements. To model a typical solar water heater with a single tank that has backup heating elements, the secondary tank is given a R-6.2 jacket to reduce the standby loss of the secondary tank. R-6.2 is the highest R-value allowable without causing OS-HPXML validation error.

Table 138. Water Heater Efficiency options and arguments that vary for each option of solar water heaters.

Option name	`solar_-thermal_-collector_-azimuth`	`solar_-thermal_-collector_-tilt`	`water_-heater_-fuel_-type`	`water_-heater_-efficiency_-type`	`water_-heater_-recovery_-efficiency`	`water_-heater_-jacket_-rvalue`
Solar Thermal, 40 sqft, East, Roof Pitch, Electric Standard Backup	90	roofpitch	electricity	0.97	0.98	6.2
Solar Thermal, 40 sqft, North, Roof Pitch, Electric Standard Backup	0	roofpitch	electricity	0.97	0.98	6.2
Solar Thermal, 40 sqft, South, Roof Pitch, Electric Standard Backup	180	roofpitch	electricity	0.97	0.98	6.2
Solar Thermal, 40 sqft, South, Roof Pitch, Fuel Oil Standard Backup	180	roofpitch	fuel oil	0.62	0.78	0
Solar Thermal, 40 sqft, South, Roof Pitch, Natural Gas Standard Backup	180	roofpitch	natural gas	0.59	0.76	0

Table 138. Water Heater Efficiency options and arguments that vary for each option of solar water heaters. (continued)

Option name	solar_thermal_collector_azimuth	solar_thermal_collector_tilt	water_heater_fuel_type	water_heater_efficiency_type	water_heater_recovery_efficiency	water_heater_jacket_rvalue
Solar Thermal, 40 sqft, South, Roof Pitch, Propane Standard Backup	180	roofpitch	propane	0.59	0.76	0
Solar Thermal, 40 sqft, West, Roof Pitch, Electric Standard Backup	270	roofpitch	electricity	0.97	0.98	6.2

For the full argument definitions, see Table 139 on storage and tankless water heaters and Table 140 on solar water heaters. See the OpenStudio-HPXML Water Heating Systems and Solar Thermal documentation for the available HPXML schema elements, default values, and constraints.

Table 139. The ResStock argument definitions set in the Water Heater Efficiency characteristic

Name	Required	Units	Type	Choices	Description
water_heater_type	true		Choice	none, storage water heater, instantaneous water heater, heat pump water heater, space-heating boiler with storage tank, space-heating boiler with tankless coil	The type of water heater. Use 'none' if there is no water heater.
water_heater_fuel_type	true		Choice	electricity, natural gas, fuel oil, propane, wood, coal	The fuel type of water heater. Ignored for heat pump water heater.
water_heater_tank_volume	false	gal	Double	auto	Nominal volume of water heater tank. If not provided, the OS-HPXML default (see Conventional Storage, Heat Pump is used.)
water_backup_heaing_efficiency	false	Btu/hr	Double	auto	Backup heating capacity for a heat pump water heater. If not provided, the OS-HPXML default (see Heat Pump.)
water_heater_efficiency_type	true		Choice	EnergyFactor, UniformEnergyFactor	The efficiency type of water heater. Does not apply to space-heating boilers.
water_heater_efficiency	true		Double		Rated Energy Factor or Uniform Energy Factor. Does not apply to space-heating boilers.
water_heater_usage_bin	false		Choice	auto, very small, low, medium, high	The usage of the water heater. Only applies if Efficiency Type is UniformEnergyFactor and Type is not instantaneous water heater. Does not apply to space-heating boilers.

Table 139. The ResStock argument definitions set in the Water Heater Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
`water_heater_recovery_efficiency`	false	Frac	Double	auto	Ratio of energy delivered to water heater to the energy content of the fuel consumed by the water heater. Only used for non-electric storage water heaters.
`water_heater_heating_capacity`	false	Btu/hr	Double	auto	Heating capacity. Only applies to storage water heater and heat pump water heater (compressor). If not provided, the OS-HPXML default (see Conventional Storage, Heat Pump is used.)
`water_heater_standby_loss`	false	deg-F/hr	Double	auto	The standby loss of water heater. Only applies to space-heating boilers.
`water_heater_jacket_rvalue`	false	h-ft^2-R/Btu	Double		The jacket R-value of water heater. Doesn't apply to instantaneous water heater or space-heating boiler with tankless coil.
`water_heater_setpoint_temperature`	false	deg-F	Double	auto	The setpoint temperature of water heater.
`water_heater_num_bedrooms_served`	false	#	Integer		Number of bedrooms served (directly or indirectly) by the water heater. Only needed if single-family attached or apartment unit and it is a shared water heater serving multiple housing units. Used to apportion water heater tank losses to the unit.
`water_heater_uses_desuperheater`	false		Boolean	auto, true, false	Requires that the housing unit has a air-to-air, mini-split, or ground-to-air heat pump or a central air conditioner or mini-split air conditioner. If not provided, assumes no desuperheater.
`water_heater_tank_model_type`	false		Choice	auto, mixed, stratified	Type of tank model to use. The 'stratified' tank generally provide more accurate results, but may significantly increase run time. Applies only to storage water heater.

Table 139. The ResStock argument definitions set in the Water Heater Efficiency characteristic (continued)

Name	Required	Units	Type	Choices	Description
`water_heater_operating_mode`	false		Choice	auto, hybrid/auto, heat pump only	The water heater operating mode. The 'heat pump only' option only uses the heat pump, while 'hybrid/auto' allows the backup electric resistance to come on in high demand situations. This is ignored if a scheduled operating mode type is selected. Applies only to heat pump water heater.
`water_heater_has_flue_or_chimney`	true		String		Whether the water heater has a flue or chimney.

Table 140. The ResStock argument definitions set in the Solar Hot Water characteristic

Name	Required	Units	Type	Choices	Description
`solar_thermal_system_type`	true		Choice	none, hot water	The type of solar thermal system. Use 'none' if there is no solar thermal system.
`solar_thermal_collector_area`	true	ft^2	Double		The collector area of the solar thermal system.
`solar_thermal_collector_loop_type`	true		Choice	liquid direct, liquid indirect, passive thermosyphon	The collector loop type of the solar thermal system.
`solar_thermal_collector_type`	true		Choice	evacuated tube, single glazing black, double glazing black, integrated collector storage	The collector type of the solar thermal system.
`solar_thermal_collector_azimuth`	true	degrees	Double		The collector azimuth of the solar thermal system. Azimuth is measured clockwise from north (e.g., North=0, East=90, South=180, West=270).
`solar_thermal_collector_tilt`	true	degrees	String		The collector tilt of the solar thermal system. Can also enter, e.g., RoofPitch, RoofPitch+20, Latitude, Latitude-15, etc.
`solar_thermal_collector_rated_optical_efficiency`	true	frac	Double		The collector rated optical efficiency of the solar thermal system.
`solar_thermal_collector_rated_thermal_losses`	true	Btu/hr-ft^2-R	Double		The collector rated thermal losses of the solar thermal system.

Table 140. The ResStock argument definitions set in the Solar Hot Water characteristic (continued)

Name	Required	Units	Type	Choices	Description
`solar_thermal_storage_volume`	false	gal	Double	auto	The storage volume of the solar thermal system.
`solar_thermal_solar_fraction`	true	frac	Double		The solar fraction of the solar thermal system. If provided, overrides all other solar thermal inputs.

Distribution Assumptions

- Water heater blanket is used as a proxy for premium storage tank water heaters.
- Heat Pump Water Heaters are added in manually as they are not in the survey; all have default efficiency: Electric Heat Pump, 50 gal, 3.45 UEF.
- Solar thermal water heaters: backup is informed by secondary water heater fuel type; electric backup is assumed if no secondary water heating. All collectors are assumed 40 sqft, roof pitch; collector orientation diversity is based on rooftop solar PV orientation for those with electric backup; for fuel backup, it is assumed south-facing.
- Due to low sample sizes, fallback rules are applied, with lumping of:
  - State: Census Division RECS
  - State: Census Region
  - State: National

8.5.2 Hot Water Distribution

ResStock follows the OpenStudio-HPXML default assumptions when modeling hot water distribution, see the OpenStudio-HPXML Hot Water Distribution documentation. Pipes are not explicitly modeled for any distribution systems, and correlations are instead used for determining the amount of hot water waste and heat gains in the living space depending on the hot water distribution system type and insulation. For a recirculation distribution system, the pipe length is calculated differently and additional inputs (e.g., power rating, control type) are used to specify the recirculation pump and pipe loop length. While recirculation options are available, all housing units in the baseline are assumed to have uninsulated trunk and branch hot water distribution system with copper pipes and without recirculation or drain water heat recovery. The inputs are captured in a single housing characteristic Hot Water Distribution.

Hot Water Distribution

Description

Hot water piping material and insulation level.

Distribution Data Sources

- Engineering judgment.

Direct Conditional Dependencies

No dependencies.

Options

For the ResStock baseline baseline, all Hot Water Distribution is assumed to be “Uninsulated, trunk and branch, copper pipes.” This option specifies the following ResStock arguments.

- `hot_water_distribution_system_type` = standard
- `hot_water_distribution_recirc_control_type` = no control

- `dwhr_facilities_connected` = none
- `dwhr_equal_flow` = true
- `dwhr_efficiency` = 0.0.

For retrofit upgrades, other options are available and can be defined using the following arguments. For the argument definitions, see Table 141. See the OpenStudio-HPXML Hot Water Distribution documentation for the available HPXML schema elements, default values, and constraints.

Table 141. The ResStock argument definitions set in the Hot Water Distribution characteristic

Name	Required	Units	Type	Choices	Description
`hot_water_distribution_system_type`	true		Choice	Standard, Recirculation	The type of the hot water distribution system.
`hot_water_distribution_standard_piping_length`	false	ft	Double	auto	If the distribution system is Standard, the length of the piping.
`hot_water_distribution_recirc_control_type`	false		Choice	auto, no control, timer, temperature, presence sensor demand control, manual demand control	If the distribution system is Recirculation, the type of hot water recirculation control, if any.
`hot_water_distribution_recirc_piping_length`	false	ft	Double	auto	If the distribution system is Recirculation, the length of the recirculation piping.
`hot_water_distribution_recirc_branch_piping_length`	false	ft	Double	auto	If the distribution system is Recirculation, the length of the recirculation branch piping. If not provided, the OS-HPXML default (see Recirculation (In-Unit)) is used.
`hot_water_distribution_recirc_pump_power`	false	W	Double	auto	If the distribution system is Recirculation, the recirculation pump power.
`hot_water_distribution_pipe_r`	false	h-ft^2-R/Btu	Double	auto	Nominal R-value of the pipe insulation.
`dwhr_facilities_connected`	true		Choice	none, one, all	Which facilities are connected for the drain water heat recovery. Use 'none' if there is no drain water heat recovery system.
`dwhr_equal_flow`	false		Boolean	auto, true, false	Whether the drain water heat recovery has equal flow.
`dwhr_efficiency`	false	Frac	Double		The efficiency of the drain water heat recovery.

Distribution Assumptions
No assumptions are made.

8.5.3 Hot Water Fixtures

Following the OpenStudio-HPXML default assumption, ResStock models hot water fixtures as 60% faucets and 40% showers and baths, operating at a mixed water temperature of 105°F for all housing units. None of the fixtures are assumed to be low-flow. However, low-flow options are available as upgrades.

The fraction of low-flow fixtures adjusts the demand to account for fixture efficiency. The demand is also multiplied by a fixture usage multiplier to add diversity. The hot water fixture usage multiplier is given by a log-normal distribution of values ranging from 40% to 200% (with mean at 80%[4]) derived from the field data of 1,700 residential electric resistance water heaters in a demand management program in the U.S. Northeast census division.

Hot Water Fixtures

Description
Hot water fixture usage and flow levels.

Distribution Data Sources

- Field data from a demand management program with 1,700 residential electric resistance water heaters in the Northeast U.S. census division.

Direct Conditional Dependencies

- Usage Level.

Options
The Hot Water Fixtures options are usage bins ranging from “50% Usage” to “200% Usage” at 10% increments. For the ResStock baseline, the options are log-normally distributed between 40% and 200%, with the peak at 80%. All options have both `water_fixtures_shower_low_flow` and `water_fixtures_sink_low_flow` set to false. `water_fixtures_usage_multiplier` is set according to their option names.

For the argument definitions, see Table 142. See the OpenStudio-HPXML Water Fixtures documentation for the available HPXML schema elements, default values, and constraints.

Table 142. The ResStock argument definitions set in the Hot Water Fixtures characteristic

Name	Required	Units	Type	Choices	Description
`water_fixtures_shower_low_flow`	true		Boolean	true, false	Whether the shower fixture is low flow.
`water_fixtures_sink_low_flow`	true		Boolean	true, false	Whether the sink fixture is low flow.
`water_fixtures_usage_multiplier`	false		Double	auto	Multiplier on the hot water usage that can reflect, e.g., high/low usage occupants.

Distribution Assumptions

- A log-normal distribution was shown to match the distribution of annual energy consumption.
- The data shows appoximately a log-normal distribution. From the data, the average multiplier is 0.8 and the standard deviation is 0.2. The average multiplier was mean-shifted from 0.8 to 1 average usage.
- Low, Medium, and High usage is assigned based on the lower 25th percent, middle 50th percent, and upper 25th percent.

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[4] The 80% average multiplier resulted in a lower than expected water usage and is addressed in a later version of ResStock.

8.5.4 Hot Water Appliances

For dishwashers and clothes washers, their daily demand for hot water (in gallons per day) is calculated according to ANSI/RESNET/ICC 301 standard. The standard uses the rated values from the product EnergyGuide label and the number of bedrooms to estimate the number of annual cycles, and thus, annual energy and hot water uses. The energy and hot water uses are further adjusted for the number of occupants in a home and multiplied by an appliance usage multiplier to add diversity, representing high-usage or low-usage occupants. These usage multipliers are given by a simple, manually created distribution of values ranging from 80% to 120%, with mean centered at 100%. The energy to heat the water and distribution losses are attributed to the water heater.

The stochastic occupant model is used to produce detailed schedule inputs from the hot water fixtures and appliances. The schedules are combined with the daily demands to calculate the peak flow rate (or design level) and peak-normalized schedules. In other words, the schedules are normalized and specify when hot water is used, not how much hot water is used; when multiplied by the peak flow rate, they aggregate to the total hot water demand calculated.

8.6 Appliances

8.6.1 Usage

Modeling Approach

ResStock models the diversity of appliance usage in a couple of ways. The first way is through scaling the energy by usage multipliers. There are three usage levels—low, medium, and high—which are used to assign usage multipliers. The characteristics that use appliance-specific usage multipliers are clothes dryer, clothes washer, cooking range, dishwasher, hot water fixtures, plug load diversity, refrigerator, misc extra refrigerator, and misc freezer. See each of these subsections for the specific multipliers used to diversify their energy consumption.

The second way is through the number and timing of appliance events throughout the year, which is dealt with in the stochastic schedule generator. See Section 7.4 for more information about when and how long the events occur for different schedules.

Usage Level

Description

Usage of major appliances relative to the national average.

Distribution Data Source(s)

Engineering judgment and calibration.

Direct Conditional Dependencies

None.

Options

The options are low, medium, and high. The distribution values are 25% for low, 50% for medium, and 25% for high. These options do not assign ResStock arguments.

Distribution Assumption(s)

None.

8.6.2 Refrigeration

Modeling Approach

Refrigeration energy is modeled for both refrigerators and standalone freezers. Each of these appliances is modeled by specifying the rated annual energy and a usage multiplier. There are primary refrigerators and, sometimes, a secondary refrigerator (misc extra refrigerator). Only up to two refrigerators and up to one standalone freezer are modeled. To account for additional refrigeration, correction factors derived using the count of refrigerators (which includes mini-fridges) and freezers from RECS 2020 are applied to each state. The timeseries schedules are handled by OpenStudio-HPXML. Currently, there are weekday and weekend schedules, and monthly multipliers.

Refrigerator

Description

The presence and rated efficiency of the primary refrigerator.

Distribution Data Source(s)

Constructed using U.S. EIA 2020 RECS microdata. Age of refrigerator converted to efficiency levels using ENERGY STAR shipment-weighted efficiencies by year data from Home Energy Saver.[5]

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- State
- Tenure
- Vintage.

Options

ResStock differentiates primary refrigerators based on their efficiency level. In the baseline stock, there are seven discrete efficiency levels ranging from EF 6.7 to EF 21.9, as well as a "None" option for housing units that do not have a refrigerator. The Refrigerator characteristic sets the `refrigerator_present`, `refrigerator_location`, and `refrigerator_rated_annual_kwh` arguments (Table 143). The `refrigerator_location` argument is set to auto.

Table 143. Refrigerator options and arguments that vary for each option

Option name	`refrigerator_present`	`refrigerator_rated_annual_kwh`
EF 6.7	true	1139
EF 10.2	true	748
EF 10.5	true	727
EF 15.9	true	480
EF 17.6	true	433
EF 19.9	true	383
EF 21.9	true	348
None	false	0

For the argument definitions, see 144. See the OpenStudio-HPXML Refrigerators documentation for the available HPXML schema elements, default values, and constraints.

Table 144. The ResStock argument definitions set in the Refrigerator characteristic

Name	Required	Units	Type	Choices	Description
`refrigerator_present`	true		Boolean	true, false	Whether there is a refrigerator present.

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[5] For more information, see http://hes-documentation.lbl.gov/.

Table 144. The ResStock argument definitions set in the Refrigerator characteristic (continued)

Name	Required	Units	Type	Choices	Description
`refrigerator_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, garage, other housing unit, other heated space, other multifamily buffer space, other non-freezing space	The space type for the refrigerator location. If not provided, the OS-HPXML default (see HPXML Refrigerators) is used.
`refrigerator_rated_annual_kwh`	false	kWh/yr	Double	auto	The EnergyGuide rated annual energy consumption for a refrigerator.

Distribution Assumption(s)

The current year is assumed to be 2022. Currently, each year has its own distribution and then we average out the distributions to get the distribution for the age bins. The Energy Factor for all years are weighted equally when calculating the average distribution for the age bins. ENERGY STAR distributions from 2009 dependent on Geometry Building Type RECS, Federal Poverty Level, and Tenure are used to calculate efficiency distribution in RECS2020. ENERGY STAR Refrigerators are assumed to be 10% more efficient than standard. Due to the low sample count, the following coarsening rules are incorporated.

1. State coarsened to Census Division RECS, with AK/HI separate.
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Vintage with Vintage ACS
5. Vintage with combined 1960s
6. Vintage with combined 1960s and post 2000s
7. Federal Poverty Level coarsened every 100%
8. Federal Poverty Level coarsened every 200%
9. Census Division RECS with AK/HI separate coarsened to Census Division RECS
10. Census Division RECS to Census Region
11. Census Region to National.

Refrigerator Usage Level

Description

Refrigerator energy usage level multiplier.

Distribution Data Source(s)

- Not applicable—direct translation of the 8.6.1 Usage input file.

Direct Conditional Dependencies

- Usage Level.

Options

The refrigerator usage level is set based on the usage level characteristic. It is 95% Usage when the usage level is Low, 100% Usage when the usage level is Medium, and 105% Usage when the usage level is High. The characteristic sets the `refrigerator_usage_multiplier` argument (Table 145).

Table 145. Refrigerator options and arguments that vary for each option

Option name	`refrigerator_usage_multiplier`
95% Usage	0.95
100% Usage	1.0
105% Usage	1.05

For the argument definitions, see Table 146.

Table 146. The ResStock argument definitions set in the Refrigerator Usage Level characteristic

Name	Required	Units	Type	Choices	Description
`refrigerator_usage_multiplier`	false		Double	auto	Multiplier on the refrigerator energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

None

Misc Extra Refrigerator

Description

The presence and rated efficiency of the secondary refrigerator.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.
- Age of refrigerator converted to efficiency levels using ENERGY STAR shipment-weighted efficiencies by year data from Home Energy Saver.[6]

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- State
- Tenure
- Vintage.

Options

Extra refrigerators are specified using the same Energy Factor (EF) and annual rated kWh options as primary refrigerators. The characteristic set the `extra_refrigerator_present`, `extra_refrigerator_location`, `extra_refrigerator_rated_annual_kwh`, and `extra_refrigerator_usage_multiplier` ResStock arguments (Table 147). If an extra refrigerator is present, the location is always set to auto. The usage multiplier varies by state and is set to account for the presence of teriary refrigerators and beyond, see 148.

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[6] For more information, see http://hes-documentation.lbl.gov/.

Table 147. Misc Extra Refrigerator options and arguments that vary for each option

Option name	`extra_refrigerator_present`	`extra_refrigerator_rated_annual_kwh`
EF 6.7	true	1139
EF 10.2	true	748
EF 10.5	true	727
EF 15.9	true	480
EF 17.6	true	433
EF 19.9	true	383
EF 21.9	true	348
None	false	0

Table 148. Misc Extra Refrigerator usage multiplier varies by state.

State	`extra_refrigerator_usage_multiplier`
AK	1.80
AL	1.76
AR	1.90
AZ	1.74
CA	1.86
CO	1.85
CT	1.96
DC	2.15
DE	1.68
FL	1.87
GA	1.74
HI	1.94
IA	1.77
ID	1.62
IL	1.82
IN	1.78
KS	1.77
KY	1.80
LA	1.88
MA	2.00
MD	1.94
ME	1.88
MI	1.73
MN	1.72
MO	1.76
MS	1.85
MT	1.69
NC	1.80
ND	1.73
NE	1.85
NH	1.90
NJ	1.81
NM	1.90
NV	1.87
NY	1.91
OH	1.81

Table 148. Misc Extra Refrigerator usage multiplier varies by state.

State	`extra_refrigerator_usage_multiplier`
OK	1.86
OR	1.84
PA	1.73
RI	1.91
SC	1.83
SD	1.83
TN	1.86
TX	1.84
UT	1.78
VA	1.80
VT	1.82
WA	1.76
WI	1.74
WV	1.68
WY	1.80

For the argument definitions, see 149. See the OpenStudio-HPXML Refrigerators documentation for the available HPXML schema elements, default values, and constraints.

Table 149. The ResStock argument definitions set in the Refrigerator Usage Level characteristic

Name	Required	Units	Type	Choices	Description
`extra_refrigerator_present`	true		Boolean	true, false	Whether there is an extra refrigerator present.
`extra_refrigerator_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, garage, other housing unit, other heated space, other multifamily buffer space, other non-freezing space	The space type for the extra refrigerator location.
`extra_refrigerator_rated_annual_kwh`	false	kWh/yr	Double	auto	The EnergyGuide rated annual energy consumption for an extra refrigerator.
`extra_refrigerator_usage_multiplier`	false		Double	auto	Multiplier on the extra refrigerator energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

The current year is assumed to be 2022. Currently, each year has its own distribution and then we average out the distributions to get the distribution for the age bins. EF for all years are weighted equally when calculating the average distribution for the age bins. ENERGY STAR distributions from 2009 dependent on Geometry Building Type RECS, Federal Poverty Level, and Tenure are used to calculate efficiency distribution in RECS 2020. ENERGY STAR refrigerators assumed to be 10% more efficient than standard. Due to the low sample count, the input file is constructed by downscaling a housing unit sub-input file with a household sub-input file. The sub-input files have the following dependencies: housing unit sub-input file: dependencies = Geometry Building Type RECS, State, and Vintage, with the following fallback coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Vintage with Vintage ACS
5. Vintage with combined 1960s
6. Vintage with combined 1960s and post 2000s
7. Census Division RECS with AK/HI separate coarsened to Census Division RECS
8. Census Division RECS to Census Region.

Census Region to National Assumption: Household sub-input file : dependencies = Geometry Building Type RECS, State, Tenure, and Federal Poverty Level, with the following fallback coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Federal Poverty Level coarsened every 100%
5. Federal Poverty Level coarsened every 200%
6. Census Division RECS with AK/HI separate coarsened to Census Division RECS
7. Census Division RECS to Census Region
8. Census Region to National.

In combining the housing unit sub-input file and household sub-input file, the conditional relationships are ignored across (Heating Fuel, [Tenure, Federal Poverty Level]).

Misc Freezer

Description

The presence and rated efficiency of a standalone freezer.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- State
- Tenure.

Options

The Misc Freezer option in baseline has an EF of 12, intended to represent the national average. The characteristic sets the `freezer_present`, `freezer_location`, `freezer_rated_annual_kwh`, and `freezer_usage_multiplier` ResStock arguments (Table 150). The usage multiplier varies by state and is set to account for the presence of extra freezers, see 151.

Table 150. Misc Freezer options and arguments that vary for each option

Option name	`freezer_present`	`freezer_location`	`freezer_rated_annual_kwh`
EF 12, National Average	true	auto	935
None	false	auto	0

Table 151. Misc Freezer usage multiplier varies by state.

State	`freezer_usage_multiplier`
AK	1.27
AL	1.34
AR	1.25
AZ	1.09
CA	1.06
CO	1.06
CT	1.08
DC	1.21
DE	1.12
FL	1.04
GA	1.26
HI	1.21
IA	1.13
ID	1.38
IL	1.07
IN	1.25
KS	1.04
KY	1.19
LA	1.32
MA	1.06
MD	1.20
ME	1.09
MI	1.22
MN	1.27
MO	1.07
MS	1.34
MT	1.33
NC	1.10
ND	1.29
NE	1.19
NH	1.23
NJ	1.05
NM	1.17
NV	1.02
NY	1.06

Table 151. Misc Freezer usage multiplier varies by state.

State	`freezer_usage_multiplier`
OH	1.12
OK	1.26
OR	1.39
PA	1.18
RI	0.97
SC	1.13
SD	1.37
TN	1.25
TX	1.18
UT	1.20
VA	1.14
VT	1.25
WA	1.14
WI	1.20
WV	1.15
WY	1.32

For the argument definitions, see Table 152. See the OpenStudio-HPXML Freezers documentation for the available HPXML schema elements, default values, and constraints.

Table 152. The ResStock argument definitions set in the Refrigerator Usage Level characteristic

Name	Required	Units	Type	Choices	Description
`freezer_present`	true		Boolean	true, false	Whether there is a freezer present.
`freezer_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, garage, other housing unit, other heated space, other multifamily buffer space, other non-freezing space	The space type for the freezer location.
`freezer_rated_annual_kwh`	false	kWh/yr	Double	auto	The EnergyGuide rated annual energy consumption for a freezer.
`freezer_usage_multiplier`	false		Double	auto	Multiplier on the freezer energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

The national average EF is 12 based on the 2014 Building America house simulation protocols.

Due to the low sample count, the input file is constructed with the following coarsening order.

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH

3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Federal Poverty Level coarsened every 100%
5. Federal Poverty Level coarsened every 200%
6. Census Division RECS with AK/HI separate coarsened to Census Division RECS
7. Census Division RECS to Census Region
8. Census Region to National.

8.6.3 Cooking

Modeling Approach

ResStock models all cooking units as ranges with an integrated (non-convection) oven located in the conditioned space. Housing units can have no cooking units. The fuel options include electric induction, electric resistance, gas, and propane, although more fuel options are available in OpenStudio-HPXML, see Cooling Range/Oven. The annual energy used for cooking is calculated per the Energy Rating Rated Home in ANSI/RESNET/ICC 301-2019 (International Code Council 2019) and is further adjusted by a Cooking Range Usage Level multiplier; see Section 8.6.3. The annual energy is multiplied with a stochastically generated detailed cooking schedule based on ATUS to produce the cooking end-use load profile. See Section 7.4 for details on schedule generation.

ResStock also models the use of a range hood for cooking. However, the range hood operation does not use the cooking schedule. Instead, the range operates for one hour every day with a starting hour sampled by the Range Spot Vent Hour characteristic distribution; see Section 8.4.9.

The next sections describe the building stock distributions for cooking, their assumptions, data sources, and argument assignment.

Cooking Range

Description

Presence and fuel type of the cooking range.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- Heating Fuel
- State
- Tenure
- Vintage.

Options

ResStock baseline has four cooking range options, which include electric induction, electric resistance, natural gas, and propane, as well as a “none” option. The characteristic assigns the `cooking_range_oven_present`, `cooking_range_oven_location`, `cooking_range_oven_fuel_type`, `cooking_range_oven_is_induction`, `cooking_range_oven_is_convection` ResStock arguments (Table 155). The `cooking_range_oven_is_convection` and `cooking_range_oven_location` is always set to auto.

Table 153. Cooking Range options and arguments that vary for each option

Option name	`cooking_range_oven_present`	`cooking_range_oven_fuel_type`	`cooking_range_oven_is_induction`
Electric Induction	true	electricity	true
Electric Resistance	true	electricity	false
Gas	true	natural gas	false
None	false	natural gas	false
Propane	true	propane	false

For the argument definitions, see Table 154. See the OpenStudio-HPXML Cooking Range/Oven documentation for the available HPXML schema elements, default values, and constraints.

Table 154. The ResStock argument definitions set in the Cooking Range characteristic

Name	Required	Units	Type	Choices	Description
`cooking_range_oven_present`	true		Boolean	true, false	Whether there is a cooking range/oven present.
`cooking_range_oven_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, garage, other housing unit, other heated space, other multifamily buffer space, other non-freezing space	The space type for the cooking range/oven location.
`cooking_range_oven_fuel_type`	true		Choice	electricity, natural gas, fuel oil, propane, wood, coal	Type of fuel used by the cooking range/oven.
`cooking_range_oven_is_induction`	false		Boolean	auto, true, false	Whether the cooking range is induction.
`cooking_range_oven_is_convection`	false		Boolean	auto, true, false	Whether the oven is convection.

Distribution Assumption(s)

For Dual Fuel Range, the distribution is split equally between Electric and Natural Gas.

Due to low sample count, the input file is constructed by downscaling a housing unit sub-input file with a household sub-input file. The sub-input files have the following dependencies: housing unit sub-input file: deps = ‘Geometry Building Type RECS’, ‘State’, ‘Heating Fuel’, and ‘Vintage,’ with the following fallback coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Heating Fuel coarsened to Other Fuel, Wood and Propane combined
3. Heating Fuel coarsened to Fuel Oil, Other Fuel, Wood and Propane combined
4. Geometry Building Type RECS coarsened to SF/MF/MH
5. Geometry Building Type RECS coarsened to SF and MH/MF
6. Vintage coarsened to every 20 years before 2000 and every 10 years subsequently

7. Vintage homes built before 1960 coarsened to pre-1960
8. Vintage homes built after 2000 coarsened to 2000-20
9. Census Division RECS with AK/HI separate coarsened to Census Division RECS
10. Census Division RECS to Census Region
11. Census Region to National.

Household sub-input file : deps = ‘Geometry Building Type RECS’, ‘State’ ‘Tenure’, ‘Federal Poverty Level,’ with the following fallback coarsening order

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Federal Poverty Level coarsened every 100%
5. Federal Poverty Level coarsened every 200%
6. Census Division RECS with AK/HI separate coarsened to Census Division RECS
7. Census Division RECS to Census Region
8. Census Region to National.

In combining the housing unit sub-input file and household sub-input file, the conditional relationships are ignored across ‘Heating Fuel’ and ‘Vintage’, as well as for ‘Tenure’ and ‘Federal Poverty Level’.

Cooking Range Usage Level

Description

Cooking range energy usage level multiplier.

Distribution Data Source(s)

- Not applicable—direct translation of the Usage Level input file; see Section 8.6.1.

Direct Conditional Dependencies

- Usage Level.

Options

The cooking range usage level is set based on the usage level characteristic (Section 8.6.1). It is 80% Usage when the usage level is Low, 100% Usage when the usage level is Medium, and 120% Usage when the usage level is High. The characteristic sets the `cooking_range_oven_usage_multiplier` ResStock argument.

Table 155. Cooking Range Usage Level options and arguments that vary for each option

Option name	`cooking_range_oven_usage_multiplier`
80% Usage	0.8
100% Usage	1.0
120% Usage	1.2

For the argument definitions, see Table 156. See the OpenStudio-HPXML Refrigerators documentation for the available HPXML schema elements, default values, and constraints.

Table 156. The ResStock argument definitions set in the Cooking Range characteristic

Name	Required	Units	Type	Choices	Description
`cooking_range_oven_usage_multiplier`	false		Double	auto	Multiplier on the cooking range/oven energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

None.

8.6.4 Dishwasher

Modeling Approach

ResStock models all dishwashers as a standalone appliance located in the conditioned space with hot water supplied by the water heater. Housing units can have no dishwasher. Dishwasher performance is defined by rated annual kWh along with other EnergyGuide label information, including place setting capacity assumed to be 12, label usage (cycles per week), electric and gas rate, and annual gas cost. The number of cycles is used to calculate the annual energy and hot water use for dishwasher per the Energy Rating Rated Home in ANSI/RESNET/ICC 301-2019 Addendum A (International Code Council 2019). The total energy and hot water use are further adjusted by a Dishwasher Usage Level multiplier (Section 8.6.4) for added diversity.

The energy estimate is multiplied with a stochastically generated appliance schedule to produce the dishwasher end-use load profile. Similarly, the total hot water use is paired with a stochastic schedule to produce an appliance hot water draw schedule for the water heater. The appliance schedule and the hot water draw schedule line up in terms of the event onset, which comes from ATUS, but not the duration or magnitude, which are sampled from data from the RBSA survey (Northwest Energy Efficiency Alliance 2024). See Section 7.4 for details on schedule generation. The hot water energy for dishwasher is attributed to the hot water end use rather than the appliance.

The following subsections describe the characteristics, distributions, data sources, and arguments assigned for the dishwasher.

Dishwasher

Description

The presence and rated efficiency of the dishwasher.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- State
- Tenure
- Vintage.

Options

The ResStock baseline has two dishwasher options, one at 290 rated kWh and one at 318 rated kWh, along with a "None" option.[7] Both dishwasher options have arguments of true for `dishwasher_present`, auto for `dishwasher_location`, RatedAnnualkWh for `dishwasher_efficiency_type`, 0.12 for `dishwasher_label_electric_rate`, 1.09 for `dishwasher_label_gas_rate`, 4 for `dishwasher_label_usage`, and 12 for `dishasher_place_setting_capacity`; see Table 157.

Table 157. Dishwasher options and arguments that vary for each option

Option name	`dishwasher_efficiency`	`dishwasher_label_annual_gas_cost`
290 Rated kWh	290	23
318 Rated kWh	318	25
None	0	0

For the argument definitions, see Table 158. See the OpenStudio-HPXML Dishwasher documentation for the available HPXML schema elements, default values, and constraints.

Table 158. The ResStock argument definitions set in the Dishwasher characteristic

Name	Required	Units	Type	Choices	Description
`dishwasher_present`	true		Boolean	true, false	Whether there is a dishwasher present.
`dishwasher_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, garage, other housing unit, other heated space, other multifamily buffer space, other non-freezing space	The space type for the dishwasher location.
`dishwasher_efficiency_type`	true		Choice	RatedAnnualkWh, EnergyFactor	The efficiency type of dishwasher.
`dishwasher_efficiency`	false	RatedAnnualkWh or EnergyFactor	Double	auto	The efficiency of the dishwasher.
`dishwasher_label_electric_rate`	false	$/kWh	Double	auto	The label electric rate of the dishwasher.
`dishwasher_label_gas_rate`	false	$/therm	Double	auto	The label gas rate of the dishwasher.
`dishwasher_label_annual_gas_cost`	false	$	Double	auto	The label annual gas cost of the dishwasher.
`dishwasher_label_usage`	false	cyc/wk	Double	auto	The dishwasher loads per week.

---

[7] ResStock currently does not account for hand washing of dishes in hot water in cases where no dishwasher is present.

Table 158. The ResStock argument definitions set in the Dishwasher characteristic (continued)

Name	Required	Units	Type	Choices	Description
`dishwasher_place_setting_capacity`	false	#	Integer	auto	The number of place settings for the unit. Data obtained from manufacturer's literature.

Distribution Assumption(s)

The 2020 RECS survey does not contain ENERGY STAR rating of dishwashers. ENERGY STAR efficiency distributions with Geometry Building Type, Census Division RECS, Federal Poverty Level, and Tenure as dependencies are imported from RECS 2009.

Due to the low sample count, the input file is constructed with the following coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Federal Poverty Level coarsened every 100%
5. Federal Poverty Level coarsened every 200%
6. Vintage coarsened to every 20 years before 2000 and every 10 years subsequently
7. Vintage homes built before 1960 coarsened to pre-1960
8. Vintage homes built after 2000 coarsened to 2000–20
9. Census Division RECS with AK/HI separate coarsened to Census Division RECS
10. Census Division RECS to Census Region.

Dishwasher Usage Level

Description

Dishwasher energy usage level multiplier.

Distribution Data Source(s)

- Not applicable—direct translation of Usage Level; see Section 8.6.1.

Direct Conditional Dependencies

- Usage Level.

Options

The dishwasher usage level is set based on the usage level characteristic; see Section 8.6.1. It is 80% Usage when the usage level is Low, 100% Usage when the usage level is Medium, and 120% Usage when the usage level is High. The characteristic sets the `dishwasher_usage_multiplier` ResStock argument (Table 159).

Table 159. Dishwasher Usage Level options and arguments that vary for each option

Option name	`dishwasher_usage_multiplier`
80% Usage	0.8
100% Usage	1.0

120% Usage	1.2

For the argument definitions, see Table 160.

Table 160. The ResStock argument definitions set in the Dishwasher Usage Level characteristic

Name	Required	Units	Type	Choices	Description
`dishwasher_usage_multiplier`	false		Double	auto	Multiplier on the dishwasher energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

None.

8.6.5 Clothes Washer

Modeling Approach

ResStock models all clothes washers as a standalone appliance located in the conditioned space with hot water supplied by the water heater. Clothes Washer Presence defines whether the appliance is present in the housing unit and is created to influence the Clothes Dryer (Section 8.6.6) presence as a dependency. Clothes washer performance is defined by integrated modified Energy Factor along with other EnergyGuide label information, including rated annual kWh, capacity (volume), label usage (cycles per week), electric and gas rate, and annual gas cost.

The number of cycles is used to calculate the annual energy and hot water use for clothes washer per the Energy Rating Rated Home in ANSI/RESNET/ICC 301-2019 Addendum A (International Code Council 2019). The total energy and hot water use are further adjusted by a Clothes Washer Usage Level multiplier for added diversity.

The energy estimate is multiplied with a stochastically generated laundry schedule to produce the clothes washer end-use load profile. Similarly, the total hot water use is paired with a stochastic schedule to produce an appliance hot water draw schedule for the water heater. The appliance schedule and the hot water draw schedule line up in terms of the event onset, which comes from ATUS, but not the duration or magnitude, which are sampled from data from the RBSA survey (Northwest Energy Efficiency Alliance 2024). See Section 7.4 for details on schedule generation. The hot water energy for clothes washer is attributed to the hot water end use rather than the appliance.

The following subsections describe the characteristics, the distributions, assumptions, data sources, options, and argument assignments for clothes washers.

Clothes Washer

Description

Presence and rated efficiency of the clothes washer.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Clothes Washer Presence
- Federal Poverty Level
- Geometry Building Type RECS
- Tenure
- Vintage.

Options

ResStock has two clothes washer options in baseline, along with a "None" option. Both clothes washer options have a `clothes_washer_location` of *auto*, a `clothes_washer_efficiency_type` of *IntegratedModifiedEnergyFactor*, a `clothes_washer_label_electric_rate` of 0.1065, a `clothes_washer_gas_rate` of 1.218, and a `clothes_washer_label_usage` of 7.538462. The arguments that differ between the two options are shown in Table 161.

Table 161. Clothes Washer options and arguments that vary for each option

Option name	`clothes_washer_efficiency`	`clothes_washer_rated_annual_kwh`	`clothes_washer_label_annual_gas_cost`	`clothes_washer_capacity`
ENERGY STAR	2.07	123	9	3.68
None	0	0	0	0
Standard	0.95	387	24	3.5

For the argument definitions, see Table 162. See the OpenStudio-HPXML Clothes Washer documentation for the available HPXML schema elements, default values, and constraints.

Table 162. The ResStock argument definitions set in the Clothes Washer characteristic

Name	Required	Units	Type	Choices	Description
`clothes_washer_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, garage, other housing unit, other heated space, other multifamily buffer space, other non-freezing space	The space type for the clothes washer location.
`clothes_washer_efficiency_type`	true		Choice	ModifiedEnergyFactor, IntegratedModifiedEnergyFactor	The efficiency type of the clothes washer.
`clothes_washer_efficiency`	false	ft^3/kWh-cyc	Double	auto	The efficiency of the clothes washer.
`clothes_washer_rated_annual_kwh`	false	kWh/yr	Double	auto	The annual energy consumed by the clothes washer, as rated, obtained from the EnergyGuide label. This includes both the appliance electricity consumption and the energy required for water heating. If not provided, the OS-HPXML default (see HPXML Clothes Washer) is used.

Table 162. The ResStock argument definitions set in the Clothes Washer characteristic (continued)

Name	Required	Units	Type	Choices	Description
clothes_washer_label_electric_rate	false	$/kWh	Double	auto	The annual energy consumed by the clothes washer, as rated, obtained from the EnergyGuide label. This includes both the appliance electricity consumption and the energy required for water heating.
clothes_washer_label_gas_rate	false	$/therm	Double	auto	The annual energy consumed by the clothes washer, as rated, obtained from the EnergyGuide label. This includes both the appliance electricity consumption and the energy required for water heating. If not provided, the OS-HPXML default (see HPXML Clothes Washer) is used.
clothes_washer_label_annual_gas_cost	false	$	Double	auto	The annual cost of using the system under test conditions. Input is obtained from the EnergyGuide label.
clothes_washer_label_usage	false	cyc/wk	Double	auto	The clothes washer loads per week.
clothes_washer_capacity	false	ft^3	Double	auto	Volume of the washer drum. Obtained from the ENERGY STAR website or the manufacturer's literature.

Distribution Assumption(s)

The 2020 RECS survey does not contain ENERGY STAR rating of clothes washers. ENERGY STAR efficiency distributions with Geometry Building Type, Federal Poverty Level, and Tenure as dependencies are imported from RECS 2009. Due to low sample count, the input file is constructed by downscaling a housing unit sub-input file with a household sub-input file. The sub-input files have the following dependencies: housing unit sub-input file: dependencies = Geometry Building Type RECS, State, Clothes Washer Presence, and Vintage, with the following coarsening order:

1. Geometry Building Type RECS coarsened to SF/MF/MH
2. Geometry Building Type RECS coarsened to SF and MH/MF
3. Vintage coarsened to every 20 years before 2000 and every 10 years subsequently
4. Vintage homes built before 1960 coarsened to pre-1960
5. Vintage homes built after 2000 coarsened to 2000–20.

Household sub-input file: dependencies = Geometry Building Type RECS, State, Tenure, and Federal Poverty Level, with the following coarsening order:

1. Geometry Building Type RECS coarsened to SF/MF/MH
2. Geometry Building Type RECS coarsened to SF and MH/MF
3. Federal Poverty Level coarsened every 100%
4. Federal Poverty Level coarsened every 200%.

In combining the housing unit sub-input file and household sub-input file, the conditional relationships are ignored across Clothes Washer Presence and Vintage, as well as for Tenure and Federal Poverty Level.

Clothes Washer Presence

Description

The presence of a clothes washer in the housing unit.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- State
- Tenure
- Vintage.

Options

This characteristic determines whether there is a clothes washer present in the housing unit. The characteristic sets the `clothes_washer_present` ResStock argument (Table 163).

Table 163. Clothes Washer Presence options and arguments that vary for each option

Option name	`clothes_washer_present`
None	false
Yes	true

For the argument definitions, see Table 164.

Table 164. The ResStock argument definitions set in the Clothes Washer Presence characteristic

Name	Required	Units	Type	Choices	Description
`clothes_washer_present`	true		Boolean	true, false	Whether there is a clothes washer present.

Distribution Assumption(s)

Due to the low sample count, the input file is constructed by downscaling a housing unit sub-input file with a household sub-input file. The sub-input files have the following dependencies. Housing unit sub-input file: dependencies = Geometry Building Type RECS, State, Heating Fuel, and Vintage, with the following coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH

3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Vintage coarsened to every 20 years before 2000 and every 10 years subsequently
5. Vintage homes built before 1960 coarsened to pre-1960
6. Vintage homes built after 2000 coarsened to 2000–20
7. Census Division RECS with AK/HI separate coarsened to Census Division RECS
8. Census Division RECS to Census Region
9. Census Region to National.

Household sub-input file: dependencies = Geometry Building Type RECS, State, Tenure, and Federal Poverty Level, with the following coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Federal Poverty Level coarsened every 100%
5. Federal Poverty Level coarsened every 200%
6. Census Division RECS with AK/HI separate coarsened to Census Division RECS
7. Census Division RECS to Census Region
8. Census Region to National.

In combining the housing unit sub-input file and household sub-input file, the conditional relationships are ignored across Geometry Building Type RECS and Vintage, as well as for Tenure and Federal Poverty Level.

Clothes Washer Usage Level

Description

Clothes washer energy usage level multiplier.

Distribution Data Source(s)

Not applicable.

Direct Conditional Dependencies

- Usage Level.

Options

The clothes washer usage level is set based on the usage level (Section 8.6.1) characteristic. It is 80% Usage when the usage level is Low, 100% Usage when the usage level is Medium, and 120% Usage when the usage level is High. The characteristic sets the `clothes_washer_usage_multiplier` ResStock argument (Table 165).

Table 165. Clothes Washer Usage Level options and arguments that vary for each option

Option name	`clothes_washer_usage_multiplier`
80% Usage	0.8
100% Usage	1.0
120% Usage	1.2

For the argument definitions, see Table 166.

Table 166. The ResStock argument definitions set in the Clothes Washer Usage Level characteristic

Name	Required	Units	Type	Choices	Description
`clothes_washer_usage_multiplier`	false		Double	auto	Multiplier on the clothes washer energy and hot water usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

- Engineering judgment.

8.6.6 Clothes Dryer

Modeling Approach

A clothes dryer is an in-unit residential appliance for drying clothes. Clothes dryers impact energy through the direct use of running the appliance. Clothes dryers in shared spaces and common areas of multifamily buildings are not currently captured in ResStock. Vented clothes dryers will result in increased infiltration to the conditioned space during dryer operation.

ResStock models clothes dryers with different heating fuels (Natural Gas, Electric, and Propane). Uses the *CombinedEnergyFactor* in OpenStudio-HPXML to specify the performance of each fuel.

The schedule of the clothes dryer usage is based on the American Time Use Survey data. The clothes dryer is scheduled to start immediately after the clothes washer ends its cycle. The duration of the clothes dryer is based on distributions from RBSA (Northwest Energy Efficiency Alliance 2024). See Section 7.4 for details on schedule generation.

ResStock provides distributions for what housing units have a clothes dryer, the fuel of the dryer, and clothes dryer energy multiplier in the “Clothes Dryer” and “Clothes Dryer Usage Level” characteristics.

Clothes Dryer

Description

The presence, rated efficiency, and fuel type of the clothes dryer in a housing unit.

Distribution Data Source(s)

Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Clothes Washer Presence
- Federal Poverty Level
- Geometry Building Type RECS
- Heating Fuel
- State
- Tenure.

Options

The ResStock baseline includes three dryer options: an electric dryer, a natural gas dryer, and a propane dryer. There is also a “None” option. Certain arguments are common across all three dryer options: auto for `clothes_dryer_location`, CombinedEnergyFactor for `clothes_dryer_efficiency_type`, and auto for `clothes_dryer_vented_flow_rate`. The arguments that differ across options are shown in Table 167.

Table 167. Clothes Dryer options and arguments that vary for each option

Option name	`clothes_dryer_present`	`clothes_dryer_fuel_type`	`clothes_dryer_efficiency`
Electric	true	electricity	2.70
Gas	true	natural gas	2.39
None	false	natural gas	2.70
Propane	true	propane	2.39

For the argument definitions, see Table 168. See the OpenStudio-HPXML Clothes Dryer documentation for the available HPXML schema elements, default values, and constraints.

Table 168. The ResStock argument definitions set in the Clothes Dryer characteristic

Name	Required	Units	Type	Choices	Description
`clothes_dryer_present`	true		Boolean	true, false	Whether there is a clothes dryer present.
`clothes_dryer_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, garage, other housing unit, other heated space, other multifamily buffer space, other non-freezing space	The space type for the clothes dryer location.
`clothes_dryer_fuel_type`	true		Choice	electricity, natural gas, fuel oil, propane, wood, coal	Type of fuel used by the clothes dryer.
`clothes_dryer_efficiency_type`	true		Choice	EnergyFactor, CombinedEnergyFactor	The efficiency type of the clothes dryer.
`clothes_dryer_efficiency`	false	lb/kWh	Double	auto	The efficiency of the clothes dryer.
`clothes_dryer_vented_flow_rate`	false	CFM	Double	auto	The exhaust flow rate of the vented clothes dryer.

Distribution Assumption(s)

Clothes dryer option is “None” if the clothes washer is not present.

Due to the low sample count, the input file is constructed by downscaling a housing unit sub-input file with a household sub-input file. The sub-input files have the following dependencies: housing unit sub-input file: dependencies = Geometry Building Type RECS, State, Heating Fuel, and Clothes Washer Presence, with the following fallback coarsening order:

1. State coarsened to Census Division RECS without AK, HI
2. Heating Fuel coarsened to Other Fuel, Wood and Propane combined
3. Heating Fuel coarsened to Fuel Oil, Other Fuel, Wood and Propane combined
4. Geometry Building Type RECS coarsened to SF/MF/MH

5. Geometry Building Type RECS coarsened to SF and MH/MF
6. State coarsened to Census Division RECS
7. State coarsened to Census Region
8. State coarsened to National.

Household sub-input file: dependencies = Geometry Building Type RECS, Tenure, and Federal Poverty Level, with the following fallback coarsening order:

1. State coarsened to Census Division RECS without AK, HI
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Federal Poverty Level coarsened every 100%
5. Federal Poverty Level coarsened every 200%
6. State coarsened to Census Division RECS
7. State coarsened to Census Region
8. State coarsened to National.

In combining the housing unit sub-input file and household sub-input file, the conditional relationships are ignored across Heating Fuel and Clothes Washer Presence, as well as across Tenure and Federal Poverty Level.

Clothes Dryer Usage Level

Description
Clothes dryer energy usage level multiplier.

Distribution Data Source(s)
Not applicable—direct mapping of usage level (Section 8.6.1).

Direct Conditional Dependencies

- Usage Level.

Options
The clothes dryer usage level is set based on the usage level (Section 8.6.1) characteristic. It is 80% Usage when the usage level is Low, 100% Usage when the usage level is Medium, and 120% Usage when the usage level is High. The characteristic assigns the `clothes_dryer_usage_multiplier` ResStock argument (Table 169).

Table 169. Clothes Dryer Usage Level options and arguments that vary for each option

Option name	`clothes_dryer_usage_multiplier`
80% Usage	0.8
100% Usage	1.0
120% Usage	1.2

For the argument definitions, see Table 170. See the OpenStudio-HPXML Refrigerators documentation for the available HPXML schema elements, default values, and constraints.

Table 170. The ResStock argument definitions set in the Clothes Dryer Usage Level characteristic

Name	Required	Units	Type	Choices	Description
`clothes_dryer_usage_multiplier`	false		Double	auto	Multiplier on the clothes dryer energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

None.

8.6.7 Ceiling Fan

Modeling Approach

ResStock models all ceiling fan options as a single fan operating at medium speed periodically throughout the year. The efficiency of the fans is specified at this speed and used to calculate the annual ceiling fan energy per the Energy Rating Rated Home in ANSI/RESNET/ICC 301-2019 (International Code Council 2019). The annual energy is multiplied with a stochastically generated detailed schedule to produce the ceiling fan end-use load profile. The ceiling fan schedule is created as a submetered reference schedule from RBSAM prorated by a separate occupancy schedule based on ATUS. See Section 7.4 for details on schedule generation. In the characteristic distribution, while ResStock distinguishes between the options "None" (no ceiling fan) and "Standard Efficiency, No Usage," both options lead to zero energy consumption.

Ceiling fans are characterized in a single housing characteristic. The distribution, data sources, assumptions, and argument assignment are discussed in the next subsection.

Ceiling Fan

Description

Presence and efficiency of ceiling fans.

Distribution Data Source(s)

Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014); national average used as saturation.

Direct Conditional Dependencies

- Vacancy Status.

Options

ResStock has three options for the ceiling fan characteristic: a standard efficiency ceiling fan, a standard efficiency ceiling fan that is not used, and "None." For the standard efficiency ceiling fan that is not used, as well as the "None" option, the `ceiling_fan_present` argument is set to false and the `ceiling_fan_quantity` is set to 0. The `ceiling_fan_cooling_setpoint_offset` argument is 0 for all options. The remaining arguments set by ResStock are shown in Table 171.

Table 171. Ceiling Fan options and arguments that vary for each option

Option name	`ceiling_fan_label_energy_use`	`ceiling_fan_efficiency`
None	0	0
Standard Efficiency	auto	70.4
Standard Efficiency, No usage	auto	0

For the argument definitions, see Table 172. See the OpenStudio-HPXML Ceiling Fans documentation for the available HPXML schema elements, default values, and constraints.

Table 172. The ResStock argument definitions set in the Ceiling Fan characteristic

Name	Required	Units	Type	Choices	Description
`ceiling_fan_present`	true		Boolean	true, false	Whether there are any ceiling fans.
`ceiling_fan_label_energy_use`	false	W	Double	auto	The label average energy use of the ceiling fan(s). If neither Efficiency nor Label Energy Use provided, the OS-HPXML default (see HPXML Ceiling Fans) is used.
`ceiling_fan_efficiency`	false	CFM/W	Double	auto	The efficiency rating of the ceiling fan(s) at medium speed. Only used if Label Energy Use not provided. If neither Efficiency nor Label Energy Use provided, the OS-HPXML default (see HPXML Ceiling Fans) is used.
`ceiling_fan_quantity`	false	#	Integer	auto	Total number of ceiling fans.
`ceiling_fan_cooling_setpoint_temp_offset`	false	deg-F	Double	auto	The cooling setpoint temperature offset during months when the ceiling fans are operating. Only applies if ceiling fan quantity is greater than zero.

Distribution Assumption(s)

If the unit is vacant, there is no ceiling fan energy.

8.6.8 Pool and Hot Tub

Modeling Approach

ResStock models pools and hot tubs/spas that are connected to the home's electric panel (i.e., not community/building pools). The saturation of pool, pool pump, pool heater, and hot tub/spa come from RECS 2020. The hot tub/spa pump is not modeled in ResStock. As pools in multifamily buildings are often for common use, the presence of pools are excluded from multifamily building types. All pools are assumed to have a pool pump. Hot tubs can be standalone or integrated as a bathroom fixture and therefore exist in all building types for units with hot tubs. The modeling of pool heaters, pool pumps, and hot tub/spa heaters in ResStock mostly relies on default OpenStudio-HPXML assumptions. Their annual energy is estimated using a reference calculation based on conditioned floor area and number of bedrooms, adjusted for occupants, using an equation from Hendron and Engebrecht (2010), and can be adjusted by a usage multiplier. The annual energy is then multiplied by a default simple schedule to produce the end-use load profile.

In OpenStudio-HPXML, pool and hot tub/spa heater options are electric resistance, gas-fired, and heat pump. Therefore, heaters for pools or spas using "Other Fuel" do not have any modeled energy consumption. Heat pump heaters are assumed to be five times more efficient than electric resistance. The use of pool cover or heating setpoint is approximated using a usage multiplier.

The building stock characterization distributions, data sources, assumptions, and argument assignment of pools and hot tubs are discussed in the next subsections.

Misc Pool

Description

The presence of a pool.

Distribution Data Source(s)

Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- State
- Tenure
- Vintage.

Options

The options for the Misc Pool characteristic are “Has Pool” and “None.” The characteristic assigns the `pool_present` ResStock argument (Table 173).

Table 173. Misc Pool options and arguments that vary for each option

Option name	`pool_present`
Has Pool	true
None	false

For the argument definitions, see Table 174. See the OpenStudio-HPXML Pools documentation for the available HPXML schema elements, default values, and constraints.

Table 174. The ResStock argument definitions set in the Misc Pool characteristic

Name	Required	Units	Type	Choices	Description
`pool_present`	true		Boolean	true, false	Whether there is a pool.

Distribution Assumption(s)

The only valid option for multifamily homes is None, because the pool is most likely to be part of the common load and not associated with a specific unit.

Due to the low sample count, the input file is constructed with the following fallback coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Federal Poverty Level coarsened every 100%
5. Federal Poverty Level coarsened every 200%
6. Vintage coarsened to every 20 years before 2000 and every 10 years subsequently
7. Vintage homes built before 1960 coarsened to pre-1960
8. Vintage homes built after 2000 coarsened to 2000–20
9. Census Division RECS with AK/HI separate coarsened to Census Division RECS

10. Census Division RECS to Census Region
11. Census Region to National.

Misc Pool Heater

Description

The heating fuel of the pool heater if there is a pool.

Distribution Data Source(s)

- Constructed using U.S. EIA 2020 RECS microdata.
- Constructed using the California Energy Commission 2019 Residential Appliance Saturation Study (RASS) microdata.

Direct Conditional Dependencies

- Heating Fuel
- Misc Pool.

Options

There are five options for pool heaters: Electricity, Electric Heat Pump, Natural Gas, None, and Other Fuel. The Electricity option defines a traditional electric resistance pool heater, whereas the Electric Heat Pump option uses heat pump technology for heating the pool. The "Other Fuel" pool heater option currently is currently not modeled in ResStock. The ResStock arguments assigned for each of these options is given in Table 175.

Table 175. Pool Heater options and arguments that vary for each option

Option name	`pool_heater_type`	`pool_heater_annual_kwh`	`pool_heater_annual_therm`	`pool_heater_usage_multiplier`
Electricity	electric resistance	auto	0	1.0
Electric Heat Pump	heat pump	auto	0	1.0
Natural Gas	gas fired	0	auto	1.0
None	none	0	0	0
Other Fuel	none	0	0	0

The "Other Fuel" option is assigned the same arguments as "None," and will result in no energy consumption.

For the argument definitions, see Table 176. See the OpenStudio-HPXML Pool Heater documentation for the available HPXML schema elements, default values, and constraints.

Table 176. The ResStock argument definitions set in the Pool Heater characteristic

Name	Required	Units	Type	Choices	Description
`pool_heater_type`	true		Choice	none, electric resistance, gas fired, heat pump	The type of pool heater. Use 'none' if there is no pool heater.
`pool_heater_annual_kwh`	false	kWh/yr	Double	auto	The annual energy consumption of the electric pool heater.
`pool_heater_annual_therm`	false	therm/yr	Double	auto	The annual energy consumption of the gas fired pool heater.
`pool_heater_usage_multiplier`	false		Double	auto	Multiplier on the pool heater energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

- Electric heat pump pool heater is not present in RECS 2020, so state-level RASS 2019 is used to split all pool heaters tagged "Electricity" by RECS 2020 into either electric resistance (still labeled "Electricity") and "Electric Heat Pump". Due to the low prevalence of diverse heating fuels in California, all homes with non-electric heating (including None heating) receive the same split, and electric space heated homes have their own distinct split.

Misc Pool Pump

Description

Presence and size of pool pump.

Distribution Data Source(s)

Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014); national average fraction used for saturation.

Direct Conditional Dependencies

- Misc Pool.

Options

The options for Misc Pool Pump are None and 1.0 horsepower (HP) Pump. If there is a pool, then the 1.0 HP Pump option is assigned. The characteristic assigns the `pool_pump_annual_kwh` and `pool_pump_usage_multiplier` ResStock arguments, Table 177.

Table 177. Misc Pool Pump options and arguments that vary for each option

Option name	`pool_pump_annual_kwh`	`pool_pump_usage_multiplier`
None	0	0
1.0 HP Pump	auto	1.0

For the argument definitions, see Table 178. See the OpenStudio-HPXML Pool Pump documentation for the available HPXML schema elements, default values, and constraints.

Table 178. The ResStock argument definitions set in the Misc Pool Pump characteristic

Name	Required	Units	Type	Choices	Description
`pool_pump_annual_kwh`	false	kWh/yr	Double	auto	The annual energy consumption of the pool pump.
`pool_pump_usage_multiplier`	false		Double	auto	Multiplier on the pool pump energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

None

Misc Hot Tub Spa

Description

The presence and heating fuel of a hot tub/spa at the housing unit.

Distribution Data Source(s)

Constructed using U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- Heating Fuel
- State
- Tenure.

Options

The options for the Misc Hot tub Spa characteristic are the heating fuel of the hot tub heater: Electricity, Natural gas, and Other Fuel. The None option is used when the housing unit does not have a hot tub. The characteristic assigns the `permanent_spa_present` `permanent_spa_heater_type`, `permanent_spa_pump_usage_multiplier`, `permanent_spa_heater_usage_multiplier`, `permanent_spa_pump_annual_kwh`, `permanent_spa_heater_annual_kwh`, and `permanent_spa_heater_annual_therm` ResStock arguments. The following arguments are set for the options:

- `permanent_spa_pump_usage_multiplier` is 1.0 for "Electricity" and "Natural Gas" and 0 for everything else.
- `permanent_spa_heater_usage_multiplier` is 1.0 for "Electricity" and "Natural Gas" and 0 for everything else.
- `permanent_spa_pump_annual_kwh` is auto for "Electricity" and "Natural Gas" and 0 for everything else.
- `permanent_spa_heater_annual_kwh` is auto for "Electricity" and 0 for everything else.
- `permanent_spa_heater_annual_therm` is auto for "Natural Gas" and 0 for everything else.

As shown, the “Other Fuel” option is assigned the same arguments as “None,” and will result in no energy consumption. The other arguments that vary across the arguments are in Table 179.

Table 179. Misc Hot Tub Spa options and arguments that vary for each option

Option name	`permanent_spa_present`	`permanent_spa_heater_type`
Electricity	true	electric resistance
Natural Gas	true	gas fired
None	false	none
Other Fuel	false	none

For the argument definitions, see Table 180. See the OpenStudio-HPXML Permanent Spas documentation for the available HPXML schema elements, default values, and constraints.

Table 180. The ResStock argument definitions set in the Misc Hot Tub Spa characteristic

Name	Required	Units	Type	Choices	Description
`permanent_spa_present`	true		Boolean	true, false	Whether there is a permanent spa.
`permanent_spa_pump_annual_kwh`	false	kWh/yr	Double	auto	The annual energy consumption of the permanent spa pump. If not provided, the OS-HPXML default (see Permanent Spa Pump) is used.

Table 180. The ResStock argument definitions set in the Misc Hot Tub Spa characteristic (continued)

Name	Required	Units	Type	Choices	Description
permanent_spa_pump_usage_multiplier	false		Double	auto	Multiplier on the permanent spa pump energy usage that can reflect, e.g., high/low usage occupants.
permanent_spa_heater_type	true		Choice	none, electric resistance, gas fired, heat pump	The type of permanent spa heater. Use 'none' if there is no permanent spa heater.
permanent_spa_heater_annual_kwh	false	kWh/yr	Double	auto	The annual energy consumption of the electric resistance permanent spa heater.
permanent_spa_heater_annual_therm	false	therm/yr	Double	auto	The annual energy consumption of the gas fired permanent spa heater.
permanent_spa_heater_usage_multiplier	false		Double	auto	Multiplier on the permanent spa heater energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

Due to the low sample count, the input file is constructed by downscaling a housing unit sub-input file with a household sub-input file. The sub-input files have the following dependencies:

housing unit sub-input file dependencies = Geometry Building Type RECS, State, and Heating Fuel, with the following fallback coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Heating Fuel coarsened to Other Fuel, Wood and Propane combined
3. Heating Fuel coarsened to Fuel Oil, Other Fuel, Wood and Propane combined
4. Geometry Building Type RECS coarsened to SF/MF/MH
5. Geometry Building Type RECS coarsened to SF and MH/MF
6. Census Division RECS with AK/HI separate coarsened to Census Division RECS
7. Census Division RECS to Census Region
8. Census Region to National.

Household sub-input file: dependencies = Geometry Building Type RECS, State, Tenure, and Federal Poverty Level, with the following fallback coarsening order:

1. State coarsened to Census Division RECS with AK/HI separate
2. Geometry Building Type RECS coarsened to SF/MF/MH
3. Geometry Building Type RECS coarsened to SF and MH/MF
4. Federal Poverty Level coarsened every 100%
5. Federal Poverty Level coarsened every 200%
6. Census Division RECS with AK/HI separate coarsened to Census Division RECS
7. Census Division RECS to Census Region
8. Census Region to National.

In combining the housing unit sub-input file and household sub-input file, the conditional relationships are ignored across Heating Fuel, as well as across Tenure and Federal Poverty Level.

8.6.9 Well Pump

Modeling Approach

Well pumps are used to extract potable water from a well. The 2017-2019 American Housing Surveys (**ahs**) estimated that 11% of US homes have a well pump, and that data is used to construct the characteristic distribution, which has a dependency to Census Division, PUMA Metro Status, and Geometry Building Type Height. Well pumps are also more common outside the metro areas than in metro areas, particularly within a principal city. A well pump in ResStock is modeled as a type of plug load that does not provide any latent or sensible heat to the housing units. The annual energy for well pumping is estimated based on conditioned floor area and number of bedrooms converted from occupants using an equation from 2014 Building America House Simulation Protocols (BAHSP) (Wilson, Engebrecht Metzger, et al. 2014) and can be adjusted by a usage multiplier. The annual energy is then multiplied by a default simple schedule to produce the end-use load profile.

Misc Well Pump

Description

Presence of well pump according to the use of well for domestic water source.

Distribution Data Source(s)

- 2017 and 2019 American Housing Survey (AHS) microdata.
- Core Based Statistical Area (CBSA) data based on the Feb 2013 CBSA delineation file.

Direct Conditional Dependencies

- Census Division
- PUMA Metro Status
- Geometry Building Type Height

Options

The options for the Misc Well Pump characteristic are Typical Efficiency if there is a well pump and None if there is no well pump. The characteristic sets the `misc_plug_loads_well_pump_present`, `misc_plug_loads_well_pump_usage_multiplier`, `misc_plug_loads_well_pump_2_usage_multiplier`, and `misc_plug_loads_well_pump_annual_kwh` ResStock arguments (Table 181).

The `misc_plug_loads_well_pump_usage_multiplier` argument is 1.0 for “Typical Efficiency” and 0 for “None.” The `misc_plug_loads_well_pump_2_usage_multiplier` argument is 1.0 for “Typical Efficiency” and 0 for “None.”

Table 181. Misc Well Pump options and arguments that vary for each option

Option name	`misc_plug_loads_well_pump_present`	`misc_plug_loads_well_pump_annual_kwh`
Typical Efficiency	true	auto
None	false	0

For the argument definitions, see Table 182. See the OpenStudio-HPXML Misc Loads documentation for the available HPXML schema elements, default values, and constraints.

Table 182. The ResStock argument definitions set in the Misc Well Pump characteristic

Name	Required	Units	Type	Choices	Description
`misc_plug_loads_well_pump_present`	true		Boolean	true, false	Whether there is a well pump.
`misc_plug_loads_well_pump_annual_kwh`	false	kWh/yr	Double	auto	The annual energy consumption of the well pump plug loads.
`misc_plug_loads_well_pump_usage_multiplier`	false		Double	auto	Multiplier on the well pump energy usage that can reflect, e.g., high/low usage occupants.
`misc_plug_loads_well_pump_2_usage_multiplier`	true		Double		Additional multiplier on the well pump energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

- All well pumps are assumed to have typical efficiency.
- Where the number of samples < 10, the Census Division is aggregated up to Census Region.
- AHS has data for buildings up to 7 stories tall. Buildings with 8 or more stories are assumed not to have a well pump.

8.6.10 Miscellaneous Gas Uses

Modeling Approach

ResStock models miscellaneous gas loads including fireplaces, grills, and lighting. ResStock randomly assigns these gas appliances to housing units based on saturation estimated by Wilson, Engebrecht Metzger, et al. (2014). Gas grill and gas lighting are assumed to be outdoor and therefore do not generate internal gains for the housing unit. For each gas appliance, the annual energy is estimated based on conditioned floor area and number of bedrooms converted from occupants using an equation from Hendron and Engebrecht (2010) and can be adjusted by a usage multiplier. The annual energy is then multiplied by a default simple schedule to produce the end-use load profile. The gas lighting characteristic distribution is in Section 8.7.2.

Misc Gas Fireplace

Description

Presence of a gas fireplace.

Distribution Data Source(s)

Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014); national average fraction used for saturation.

Direct Conditional Dependencies

None.

Options
The options for the Misc Gas Fireplace characteristic are either "Gas Fireplace" if the housing unit has a gas fireplace or "None" if there is no gas fireplace in the unit. The characteristic assigns the `misc_fuel_loads_fireplace_present`, `misc_fuel_loads_fireplace_frac_sensible`, `misc_fuel_loads_fireplace_frac_latent`, `misc_fuel_loads_fireplace_annual_therm`, and `misc_fuel_loads_fireplace_usage_multiplier` ResStock arguments (Table 183).

The `misc_fuel_loads_fireplace_fuel_type` argument is set to natural gas. The `misc_fuel_loads_fireplace_frac_sensible` and `misc_fuel_loads_fireplace_frac_latent` arguments are set to auto.

Table 183. Misc Gas Fireplace options and arguments that vary for each option

Option name	`misc_fuel_loads_fireplace_present`	`misc_fuel_loads_fireplace_annual_therm`	`misc_fuel_loads_fireplace_usage_multiplier`
Gas Fireplace	true	auto	1.0
None	false	0	0

For the argument definitions, see Table 184. See the OpenStudio-HPXML Fireplace documentation for the available HPXML schema elements, default values, and constraints.

Table 184. The ResStock argument definitions set in the Misc Gas Fireplace characteristic

Name	Required	Units	Type	Choices	Description
`misc_fuel_loads_fireplace_present`	true		Boolean	true, false	Whether there is fuel loads fireplace.
`misc_fuel_loads_fireplace_fuel_type`	true		Choice	natural gas, fuel oil, propane, wood, wood pellets	The fuel type of the fuel loads fireplace.
`misc_fuel_loads_fireplace_annual_therm`	false	therm/yr	Double	auto	The annual energy consumption of the fuel loads fireplace.
`misc_fuel_loads_fireplace_frac_sensible`	false	Frac	Double	auto	Fraction of fireplace residual fuel loads' internal gains that are sensible. If not provided, the OS-HPXML default (see HPXML Fuel Loads) is used.
`misc_fuel_loads_fireplace_frac_latent`	false	Frac	Double	auto	Fraction of fireplace residual fuel loads' internal gains that are latent.
`misc_fuel_loads_fireplace_usage_multiplier`	false		Double	auto	Multiplier on the fuel loads fireplace energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)
None.

Misc Gas Grill

Description

Presence of a gas grill.

Distribution Data Source(s)

Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014); national average fraction used for saturation.

Direct Conditional Dependencies

None.

Options

The options for Misc Gas Grill are "Gas Grill" if the housing unit has a gas grill or "None" if the housing unit does not have a gas grill. The characteristic sets the `misc_fuel_loads_grill_present`, `misc_fuel_loads_grill_fuel_type`, `misc_fuel_loads_grill_annual_therm`, and `misc_fuel_loads_grill_usage_multiplier` ResStock arguments (Table 185). The `misc_fuel_loads_grill_fuel_type` is always set to natural gas.

Table 185. Misc Gas Grill options and arguments that vary for each option

Option name	`misc_fuel_loads_grill_present`	`misc_fuel_loads_grill_annual_therm`	`misc_fuel_loads_grill_usage_multiplier`
Gas Grill	true	auto	1.0
None	false	0	0

For the argument definitions, see Table 186. See the OpenStudio-HPXML Fuel Loads documentation for the available HPXML schema elements, default values, and constraints.

Table 186. The ResStock argument definitions set in the Misc Gas Grill characteristic

Name	Required	Units	Type	Choices	Description
`misc_fuel_loads_grill_present`	true		Boolean	true, false	Whether there is a fuel loads grill.
`misc_fuel_loads_grill_fuel_type`	true		Choice	natural gas, fuel oil, propane, wood, wood pellets	The fuel type of the fuel loads grill.
`misc_fuel_loads_grill_annual_therm`	false	therm/yr	Double	auto	The annual energy consumption of the fuel loads grill.
`misc_fuel_loads_grill_usage_multiplier`	false		Double	auto	Multiplier on the fuel loads grill energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

None.

8.6.11 PV

Modeling Approach

ResStock models residential photovoltaic (PV) solar panels based on data from Lawrence Berkeley National Laboratory's (LBNL) 2020 Tracking the Sun report (Barbose and Darghouth 2019) and a 2020 PV report by Wood Mackenzie (Woods Mackenzie 2020). However, the data excludes Alaska and Hawaii, the latter of which has one of the largest number of solar installations by state. Therefore, the PV penetration in Hawaii is added based on 2023's EIA form 861. ResStock only models rooftop solar for occupied single-family detached homes. This means ResStock does not model ground-mounted solar or solar installed in other building types, such as community solar shared among multifamily units, although that modeling capability exists in OpenStudio-HPXML. This also means ResStock, which estimates the rooftop solar penetration at less than 1% of all housing units, is most likely underestimating the total installed capacity nationally. In addition to the presence of rooftop solar (Section 8.6.11), ResStock also characterizes the orientation (Section 8.6.11) and system capacity (Section 8.6.11), using LBNL's 2020 Tracking the Sun report. The system size or modeled capacity does not necessarily align with the available roof space of the housing units.

The PV modeling capability and default inputs are primarily adopted from NREL's PVWatts model. ResStock calculates the energy production based on the solar irradiation information in the weather file and the characteristics of the PV array. In the ResStock baseline, all PV systems are modeled as roof-mounted, fixed-axis standard modules tilted at roof pitch with a 14% overall derate factor and a 96% inverter efficiency. The derate factor encompasses loss from soiling, shading, wiring, mismatch, degradation, and more according to the PVWatts documentation (Dobos 2014).

Has PV

Description

Presence of a rooftop photovoltaic system.

Distribution Data Source(s)

Constructed using ACS population and data from dGen on PV installation that combines LBNL's 2020 Tracking the Sun (Barbose and Darghouth 2019) and Wood Mackenzie's 2020 Q4 PV report (Woods Mackenzie 2020; prepared on Jun 22, 2021). The PV penetration in Hawaii is from EIA form 861.

Direct Conditional Dependencies

- County
- Geometry Building Type RECS
- Vacancy Status.

Options

The options for Has PV are "Yes" if the housing unit has a rooftop PV system and "No" if the housing unit does not have a rooftop PV system.

Distribution Assumption(s)

Imposed an upper bound of 14 kWDC, which contains 95% of all installations. Counties with source_count <10 are backfilled with aggregates at the state level. Distribution based on all installations is applied only to occupied single-family detached homes; actual distribution for single-family detached homes may be higher. PV is not modeled in AK. No data have been identified.

For Hawaii, EIA Form 861 reports the number of residential utility customers with rooftop PV in the Net Metering 2023 worksheet and the total number of residential utility customers in Sales Ult Cust 2023 worksheet. Taking the ratio of these two gives us the fraction of homes with rooftop PV. We place the additional constraint that all of these rooftop PV customers are in single-family detached homes. Because Hawaii is composed of multiple islands, the four electric utilities in Hawaii (and which report to EIA Form 861) approximately align with the county boundaries with Hawaii, Honolulu, and Kauai having one county for one electric utility, and both Maui and Kalawao mapping to the same electric utility, so we we develop distinct PV saturation rates for each county in Hawaii (note Kalawao has population 81 people and is located on the island of Maui).

PV Orientation

Description

The orientation of the PV system.

Distribution Data Source(s)

Constructed using LBNL's 2020 Tracking the Sun report (Barbose and Darghouth 2019).

Direct Conditional Dependencies

- Has PV.

Options

The options for PV orientation are the cardinal and subcardinal directions and "None" for housing units that do not have PV systems. The characteristic sets the `pv_system_array_azimuth` and `pv_system_2_array_azimuth` arguments (Table 187). The `pv_system_2_array_azimuth` argument is always set to 0.

Table 187. PV Orientation options and arguments that vary for each option

Option name	`pv_system_array_azimuth`
East	90
None	180
North	0
Northeast	45
Northwest	315
South	180
Southeast 135	
Southwest	225
West	270

For the argument definitions, see Table 188. See the OpenStudio-HPXML Photovoltaics documentation for the available HPXML schema elements, default values, and constraints.

Table 188. The ResStock argument definitions set in the PV Orientation characteristic

Name	Required	Units	Type	Description
`pv_system_array_azimuth`	true	degrees	Double	Array azimuth of the PV system. Azimuth is measured clockwise from north (e.g., North=0, East=90, South=180, West=270).
`pv_system_2_array_azimuth`	true	degrees	Double	Array azimuth of the second PV system. Azimuth is measured clockwise from north (e.g., North=0, East=90, South=180, West=270).

Distribution Assumption(s)

- PV orientation mapped based on the azimuth angle of the primary array (180° is south-facing).
- The orientation is not aligned with the roof deck's normal directions from the Orientation characteristic (Section 8.2.1).

PV System Size

Description

The size of the PV system.

Distribution Data Source(s)

Constructed using LBNL's 2020 Tracking the Sun report (Barbose and Darghouth 2019).

Direct Conditional Dependencies

- Has PV
- State.

Options

The options for the PV System Size characteristic are a set of PV system sizes ranging from 1–13 kWDC. The characteristic assigns the `pv_system_present`, `pv_system_module_type`, `pv_system_location`, `pv_system_tracking`, `pv_system_array_tilt`, `pv_system_max_power_output`, `pv_system_inverter_efficiency`, `pv_system_system_losses_fraction`, `pv_system_2_present`, `pv_system_2_module_type`, `pv_system_2_location`, `pv_system_2_tracking`, `pv_system_2_array_tilt`, and `pv_system_2_max_power_output` ResStock arguments (Table 189).

The following arguments are set to auto: `pv_system_module_type`, `pv_system_tracking`, `pv_system_max_power_output`, `pv_system_inverter_efficiency`, `pv_system_system_losses_fraction`, `pv_system_2_module_type`, `pv_system_2_tracking`, and `pv_system_2_max_power_output`. The `pv_system_location` and `pv_system_2_location` are set to roof. `pv_system_array_tilt` and `pv_system_2_array_tilt` are always set to roofpitch. `pv_system_2_present` is always false. `pv_system_2_max_power_output` is always 0.

Table 189. PV System Size options and arguments that vary for each option

Option name	`pv_system_present`	`pv_system_max_power_output`
1.0 kWDC	true	100
3.0 kWDC	true	3,000
5.0 kWDC	true	5,000
7.0 kWDC	true	7,000
9.0 kWDC	true	9,000
11.0 kWDC	true	11,000
13.0 kWDC	true	13,000
None	false	0

For the argument definitions, see Table 190. See the OpenStudio-HPXML Photovoltaics documentation for the available HPXML schema elements, default values, and constraints.

Table 190. The ResStock argument definitions set in the PV System Size characteristic

Name	Required	Units	Type	Choices	Description
`pv_system_present`	true		Boolean	true, false	Whether there is a PV system present.
`pv_system_module_type`	false		Choice	auto, standard, premium, thin film	Module type of the PV system.
`pv_system_location`	false		Choice	auto, roof, ground	Location of the PV system.

Table 190. The ResStock argument definitions set in the PV System Size characteristic (continued)

Name	Required	Units	Type	Choices	Description
`pv_system_tracking`	false		Choice	auto, fixed, 1-axis, 1-axis backtracked, 2-axis	Type of tracking for the PV system.
`pv_system_array_tilt`	true	degrees	String		Array tilt of the PV system. Can also enter, e.g., RoofPitch, RoofPitch+20, Latitude, Latitude-15, etc.
`pv_system_max_power_output`	true	W	Double		Maximum power output of the PV system. For a shared system, this is the total building maximum power output.
`pv_system_inverter_efficiency`	false	Frac	Double	auto	Inverter efficiency of the PV system. If there are two PV systems, this will apply to both.
`pv_system_system_losses_fraction`	false	Frac	Double	auto	System losses fraction of the PV system. If there are two PV systems, this will apply to both.
`pv_system_2_present`	true		Boolean	true, false	Whether there is a second PV system present.
`pv_system_2_module_type`	false		Choice	auto, standard, premium, thin film	Module type of the second PV system.
`pv_system_2_location`	false		Choice	auto, roof, ground	Location of the second PV system.
`pv_system_2_tracking`	false		Choice	auto, fixed, 1-axis, 1-axis backtracked, 2-axis	Type of tracking for the second PV system.
`pv_system_2_array_tilt`	true	degrees	String		Array tilt of the second PV system. Can also enter, e.g., RoofPitch, RoofPitch+20, Latitude, Latitude-15, etc.
`pv_system_2_max_power_output`	true	W	Double		Maximum power output of the second PV system. For a shared system, this is the total building maximum power output.

Distribution Assumption(s)

Installations of unknown mount type are assumed to be rooftop. States without data are backfilled with aggregates at the Census Region. “East South Central” assumed the same distribution as “West South Central.” PV is not modeled in AK. The Option=None is set so that an error is thrown if PV is modeled as an argument.

8.6.12 Additional Capabilities

This section describes the additional modeling capabilities in OpenStudio-HPXML/ResStock that are not yet fully deployed in the ResStock baseline. These include batteries and dehumidifiers. These loads at present are not available in the baseline but can be modeled as upgrade measures. This is because their characteristic distribution is not yet fully characterized but is instead set to 100% None.

Modeling Approach

Batteries in ResStock use a standalone Lithium-ion battery model whose performance is characterized by voltage rating, power rating, installed capacity, usable capacity, round trip efficiency, and installed location. The battery can charge and discharge based on a detailed schedule input or be controlled to capture net solar production and modulate whole-home load in a home with PV.

A dehumidifier is a device used to maintain a reasonable relative humidity in the home. ResStock models a dehumidifier as a portable device located in the conditioned space of the home. Other inputs to this model include capacity, rated efficiency, and relative humidity setpoint. The dehumidifier model is not intended to handle, e.g., a wet basement or crawlspace where there is significant moisture from the ground.

Battery

Description

Presence, size, location, and efficiency of an on-site battery.

Distribution Data Source(s)

Not applicable.

Direct Conditional Dependencies

Not applicable.

Options

Currently only the option “None” is defined in the ResStock baseline. This option is nullified by setting the `battery_present` to 0. Other options are available for use in an upgrade measure, and the argument table shows how the options can be defined (Table 191). The characteristic assigns the `battery_location`, `battery_power`, `battery_capacity`, and `battery_round_trip_efficiency` ResStock arguments.

Table 191. The ResStock argument definitions set in the Battery characteristic

Name	Required	Units	Type	Choices	Description
	true		Boolean	true, false	Whether there is a lithium ion battery present.
`battery_location`	false		Choice	auto, conditioned space, basement—conditioned, basement—unconditioned, crawlspace, crawlspace—vented, crawlspace—unvented, crawlspace—conditioned, attic, attic—vented, attic—unvented, garage, outside	The space type for the lithium ion battery location.
`battery_power`	false	W	Double	auto	The rated power output of the lithium ion battery.
`battery_capacity`	false	kWh	Double	auto	The nominal capacity of the lithium ion battery.
`battery_usable_capacity`	false	kWh	Double	auto	The usable capacity of the lithium ion battery.

Table 191. The ResStock argument definitions set in the Battery characteristic (continued)

Name	Required	Units	Type	Choices	Description
`battery_round_trip_efficiency`	false	Frac	Double	auto	The round trip efficiency of the lithium ion battery.

Distribution Assumption(s)

Not applicable.

Dehumidifier

Description

Presence, water removal rate, and humidity setpoint of the dehumidifier.

Distribution Data Source(s)

Not applicable.

Direct Conditional Dependencies

Not applicable.

Options

Currently only the option "None" is defined in the ResStock baseline. This option is nullified by setting the `dehumidifier_efficiency` to 0. Other options are available for use in an upgrade measure, and the argument table shows how the options can be defined (Table 192). The characteristic sets the `dehumidifier_type`, `dehumidifier_efficiency_type`, `dehumidifier_efficiency`, `dehumidifier_capacity`, `dehumidifier_rh_setpoint`, and `dehumidifier_fraction_dehumidification_load_served` ResStock arguments.

Table 192. The ResStock argument definitions set in the Dehumidifier characteristic

Name	Required	Units	Type	Choices	Description
`dehumidifier_type`	true		Choice	none, portable, whole-home	The type of dehumidifier.
`dehumidifier_efficiency_type`	true		Choice	Energy Factor, IntegratedEnergyFactor	The efficiency type of dehumidifier.
`dehumidifier_efficiency`	true	L/kWh	Double		The efficiency of the dehumidifier.
`dehumidifier_capacity`	true	pint/day	Double		The capacity (water removal rate) of the dehumidifier.
`dehumidifier_rh_setpoint`	true	Frac	Double		The relative humidity setpoint of the dehumidifier.
`dehumidifier_fraction_dehumidification_load_served`	true	Frac	Double		The dehumidification load served fraction of the dehumidifier.

Distribution Assumption(s)

Not applicable

8.7 Lighting

Lighting in ResStock covers interior lighting within the housing unit, and for single-family homes, attached garage and exterior lighting that is metered at the home. Multifamily common space, parking garage, and exterior lighting are excluded from ResStock.

8.7.1 Modeling Approach

Five ResStock input files provide the options and arguments for lighting, but only two are currently in use:

- Lighting—Electric lighting: interior, exterior, and garage
- Misc Gas Lighting—Exterior natural gas lighting
- Holiday Lighting—Not used
- Lighting Interior Use—Not used
- Lighting Other Use—Not used.

ResStock models three lighting technologies: light-emitting diodes (LEDs), incandescent bulbs, and compact florescent (CFL) bulbs. The technologies are represented as a fraction of the number of light bulbs in the home covered by each technology.

Separately, outside these input files, ResStock provides schedules for lighting based on the occupancy schedule generator (Section 7.4).

8.7.2 Lighting Characteristics

Lighting

Description

Specifies the type of lighting technology used in the housing unit.

Distribution Data Source(s)

- U.S. EIA 2020 RECS microdata.

Direct Conditional Dependencies

- State
- Geometry Building Type RECS.

Options

In ResStock there are three options available for lighting: *100% CFL*, *100% LED*, and *100% Incandescent*. The assumption in ResStock is that all lighting within a home is of the same technology, both interior and exterior. Across all three options, the argument *lighting_present = true*. Each ResStock option specifies the corresponding ResStock arguments for interior, exterior, and garage of the building. All non-specified arguments in the table below for other technologies are set to zero. In OpenStudio-HPXML, all lighting that is not specified as one of the set technologies (e.g., CFL or LED) is assumed to be incandescent, so the *100% Incandescent* option has all technology options set to 0 (i.e., there is no explicit incandescent option in OpenStudio-HPXML).

Table 193. Lighting options and arguments that vary for each option

Option name	Interior argument	Exterior argument	Garage argument
100% CFL	*lighting_interior_fraction_cfl* = 1	*lighting_exterior_fraction_cfl* = 1	*lighting_garage_fraction_cfl* = 1
100% Incandescent	all arguments = 0	all arguments = 0	all arguments = 0
100% LED	*lighting_interior_fraction_led* = 1	*lighting_exterior_fraction_led* = 1	*lighting_garage_fraction_led* = 1

For the argument definitions, see Table 194. See the OpenStudio-HPXML Lighting documentation for the available HPXML schema elements, default values, and constraints.

Table 194. The ResStock arguments set in the Lighting characteristic

Name	Required	Units	Type	Choices	Description
`lighting_present`	true		Boolean	true, false	Whether there is lighting energy use.
`lighting_interior_fraction_cfl`	true	Double			Fraction of all lamps (interior) that are compact fluorescent. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.
`lighting_interior_fraction_lfl`	true	Double			Fraction of all lamps (interior) that are linear fluorescent. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.
`lighting_interior_fraction_led`	true	Double			Fraction of all lamps (interior) that are light emitting diodes. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.
`lighting_exterior_fraction_cfl`	true	Double			Fraction of all lamps (exterior) that are compact fluorescent. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.
`lighting_exterior_fraction_lfl`	true	Double			Fraction of all lamps (exterior) that are linear fluorescent. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.
`lighting_exterior_fraction_led`	true	Double			Fraction of all lamps (exterior) that are light emitting diodes. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.
`lighting_garage_fraction_cfl`	true	Double			Fraction of all lamps (garage) that are compact fluorescent. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.
`lighting_garage_fraction_lfl`	true	Double			Fraction of all lamps (garage) that are linear fluorescent. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.
`lighting_garage_fraction_led`	true	Double			Fraction of all lamps (garage) that are light emitting diodes. Lighting not specified as CFL, LFL, or LED is assumed to be incandescent.

Distribution Assumption(s)

- Qualitative lamp type fractions in each household surveyed are distributed to three options representing 100% incandescent, 100% CFl, and 100% LED lamp type options.
- Qualitative portion of inside light bulbs in 2020 RECS microdata is mapped to quantative percentage as: None: 0%; Some: 20%; About half: 50%; Most: 80%; All: 100%. Then the sum of three types of lighting options is normalized to 100%.

Miscellaneous Gas Lighting

Description

Presence of exterior natural gas lighting.

Distribution Data Source(s)

- Building America House Simulation Protocols (Wilson, Engebrecht Metzger, et al. 2014); national average fraction used for saturation.

Direct Conditional Dependencies

None.

Options

ResStock has two options for Misc Gas Lighting (Table 195): *None* or *Gas Lighting*. For both of these options, the *misc_fuel_loads_lighting_fuel_type* ResStock argument is set to *natural gas*.

Table 195. Misc Gas Lighting options and arguments that vary for each option

Option name	Stock saturation	`misc_fuel_loads_lighting_present`	`misc_fuel_loads_lighting_annual_therm`	`misc_fuel_loads_lighting_usage_multiplier`
Gas Lighting	1.2%	true	auto	1.0
None	98.8%	false	0	0

For the argument definitions, see Table 196. See the OpenStudio-HPXML Misc Fuel Loads documentation for the available HPXML schema elements, default values, and constraints.

Table 196. The ResStock arguments set in the Misc Gas Lighting characteristic

Name	Required	Units	Type	Choices	Description
`misc_fuel_loads_lighting_present`	true		Boolean	true, false	Whether there is fuel loads lighting.
`misc_fuel_loads_lighting_fuel_type`	true		Choice	natural gas, fuel oil, propane, wood, wood pellets	The fuel type of the fuel loads lighting.
`misc_fuel_loads_lighting_annual_therm`	false	therm/yr	Double	auto	The annual energy consumption of the fuel loads lighting.
`misc_fuel_loads_lighting_usage_multiplier`	false		Double	auto	Multiplier on the fuel loads lighting energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

None.

Holiday Lighting

Description

Holiday lighting presence and use. Not currently used in ResStock.

Distribution Data Source(s)

Not applicable.

Direct Conditional Dependencies

None.

Options

The *No Exterior Use* option is assigned to all buildings in ResStock (Table 198).

Table 197. The ResStock arguments set in the Holiday Lighting characteristic

Option name	`holiday_lighting_present`	`holiday_lighting_daily_kwh`	`holiday_lighting_period`
No Exterior Use	false	0	auto

For the argument definitions, see Table 198. See the OpenStudio-HPXML Exterior Holiday Lighting documentation for the available HPXML schema elements, default values, and constraints.

Table 198. The ResStock arguments set in the Holiday Lighting characteristic

Name	Required	Units	Type	Choices	Description
`holiday_lighting_present`	true		Boolean	true, false	Whether there is holiday lighting.
`holiday_lighting_daily_kwh`	false	kWh/day	Double	auto	The daily energy consumption for holiday lighting (exterior).
`holiday_lighting_period`	false		String	auto	Enter a date like 'Nov 25–Jan 5'.

Distribution Assumption(s)

None.

Lighting Interior Use

Description

Interior lighting usage relative to the national average. Sampled for buildings, but no longer used for ResStock models. Instead, lighting use schedules are controlled by the ResStock schedule generator.

Distribution Data Source(s)

Not applicable.

Direct Conditional Dependencies

None.

Options
All buildings are assigned the option *100% Usage*, which sets the ResStock argument *lighting_interior_usage_multiplier* to 1 (the OpenStudio-HPXML default) (Table 199).

Table 199. The ResStock arguments set in the Lighting Interior Use characteristic

Name	Required	Units	Type	Choices	Description
`lighting_interior_usage_multiplier`	false		Double	auto	Multiplier on the lighting energy usage (interior) that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

- This parameter for adding diversity to lighting usage patterns is not currently used.

Lighting Other Use

Description
Exterior and garage lighting usage relative to the national average. Sampled for buildings, but no longer used for ResStock models. Instead, lighting use schedules are controlled by the ResStock schedule generator.

Distribution Data Source(s)
Not applicable.

Direct Conditional Dependencies
None.

Options
All buildings are assigned the option *100% Usage*, which sets the ResStock arguments *lighting_exterior_usage_multiplier* and *lighting_garage_usage_multiplier* to 1 (the OS-HPXML default).

For the argument definitions, see Table 200. See the OpenStudio-HPXML Lighting documentation for the available HPXML schema elements, default values, and constraints.

Table 200. The ResStock arguments set in the Lighting Interior Use characteristic

Name	Required	Units	Type	Choices	Description
`lighting_exterior_usage_multiplier`	false		Double	auto	Multiplier on the lighting energy usage (exterior) that can reflect, e.g., high/low usage occupants.
`lighting_garage_usage_multiplier`	false		Double	auto	Multiplier on the lighting energy usage (garage) that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

- This parameter for adding diversity to lighting usage patterns is not currently used.

8.8 Plug Loads

In ResStock, plug loads capture electric loads in the home that are not explicitly modeled on their own. Examples of plug loads includes things like microwaves, garbage disposals, toasters, fish tanks, cell phones, televisions, and portable humidifiers. Most of these items are not modeled explicitly under the plug loads modeling in ResStock, but instead are captured through a regression equation from RECS applied to ResStock homes, with some additional variability inserted on top to mimic the real-world variation and diversity that exist within these loads. These regressions form the usage multipliers that are applied to the default OpenStudio-HPXML calculations for plug loads. Based on ANSI/RESNET/ICC 301-2019, the plug load calculation estimates TV load based on the number of bedrooms converted from occupants and other load based on conditioned floor area. Two input files control plug loads in ResStock: Plug Loads and Plug Load Diversity.

Plug Loads

Description

Plug load usage level as a percentage of the national average.

Distribution Data Source(s)

- U.S. EIA 2015 RECS microdata.

Direct Conditional Dependencies

- Census Division RECS
- Geometry Building Type RECS.

Options

ResStock provides a range of percentages for plug load usage that are multipliers compared to national average plug load energy use (Table 201). Several ResStock arguments are constant across all options:

- `misc_plug_loads_television_present` = true
- `misc_plug_loads_television_annual_kwh` = auto
- `misc_plug_loads_other_annual_kwh` = auto
- `misc_plug_loads_other_frac_sensible` = 0.93
- `misc_plug_loads_other_frac_latent` = 0.021.

Table 201. The ResStock arguments set in the Plug Loads characteristic

Option name	`misc_plug_loads_television_usage_multiplier`	`misc_plug_loads_other_usage_multiplier`
78%	0.78	0.78
79%	0.79	0.79
82%	0.82	0.82
84%	0.84	0.84
85%	0.85	0.85
86%	0.86	0.86
89%	0.89	0.89
91%	0.91	0.91
94%	0.94	0.94
95%	0.95	0.95
96%	0.96	0.96
97%	0.97	0.97
99%	0.99	0.99
100%	1.0	1.0
101%	1.01	1.01
102%	1.02	1.02
103%	1.03	1.03

Table 201. The ResStock arguments set in the Plug Loads characteristic (continued)

Option name	`misc_plug_loads_television_usage_multiplier`	`misc_plug_loads_other_usage_multiplier`
104%	1.04	1.04
105%	1.05	1.05
106%	1.06	1.06
108%	1.08	1.08
110%	1.1	1.1
113%	1.13	1.13
119%	1.19	1.19
121%	1.21	1.21
123%	1.23	1.23
134%	1.34	1.34
137%	1.37	1.37
140%	1.4	1.4
144%	1.44	1.44
166%	1.66	1.66

For the argument definitions, see Table 202. See the OpenStudio-HPXML Plug Loads documentation for the available HPXML schema elements, default values, and constraints.

Table 202. The ResStock arguments set in the Plug Loads Use characteristic

Name	Required	Units	Type	Choices	Description
`misc_plug_loads_television_present`	true		Boolean	true, false	Whether there are televisions.
`misc_plug_loads_television_annual_kwh`	false	kWh/yr	Double	auto	The annual energy consumption of the television plug loads.
`misc_plug_loads_television_usage_multiplier`	false		Double	auto	Multiplier on the television energy usage that can reflect, e.g., high-/low usage occupants.
`misc_plug_loads_other_annual_kwh`	false	kWh/yr	Double	auto	The annual energy consumption of the other residual plug loads.
`misc_plug_loads_other_frac_sensible`	false	Frac	Double	auto	Fraction of other residual plug loads' internal gains that are sensible.
`misc_plug_loads_other_frac_latent`	false	Frac	Double	auto	Fraction of other residual plug loads' internal gains that are latent.
`misc_plug_loads_other_usage_multiplier`	false		Double	auto	Multiplier on the other energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

- Multipliers are based on ratio of the ResStock miscellaneous electric loads (MELS) regression equations and the MELS modeled in RECS.

Plug Load Diversity

Description

Plug load diversity multiplier intended to add additional variation in plug load profiles across all simulations.

Distribution Data Source(s)

- Engineering judgment, calibration.

Direct Conditional Dependencies

- Usage Level.

Option(s)

Three different levels of plug load diversity are added on top of the regional multipliers from the Plug Loads input file (Table 203).

Table 203. The ResStock arguments set in the Plug Loads Diversity characteristic

Option name	`misc_plug_loads_television_2_usage_multiplier`	`misc_plug_loads_other_2_usage_multiplier`
50%	0.5	0.5
100%	1.0	1.0
200%	2.0	2.0

For the argument definitions, see Table 204. See the OpenStudio-HPXML Plug Loads documentation for the available HPXML schema elements, default values, and constraints.

Table 204. The ResStock arguments set in the Plug Load Diversity Use characteristic

Name	Required	Units	Type	Choices	Description
`misc_plug_loads_television_2_usage_multiplier`	true		Double		Additional multiplier on the television energy usage that can reflect, e.g., high/low usage occupants.
`misc_plug_loads_other_2_usage_multiplier`	true		Double		Additional multiplier on the other energy usage that can reflect, e.g., high/low usage occupants.

Distribution Assumption(s)

None.

8.9 Electric Vehicles

8.9.1 Modeling Approach

The electric vehicle (EV) capabilities in ResStock were largely created under a joint project to ensure consistency between model inputs and outputs for ResStock and Transportation Energy & Mobility Pathway Options Model[8]

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[8] https://www.nrel.gov/transportation/tempo-model.html

(TEMPO), Muratori et al. 2021. The EV model in ResStock uses an EnergyPlus battery object to simulate the charging and discharging. Since a battery is typically associated with being attached to the building and not being driven around, the energy being discharged is ignored in the energy reporting as the electric vehicle is assumed to only draw energy from the dwelling unit. No vehicle-to-building energy exhange is considered in the baseline model. ResStock specifies if a specific unit has an electric vehicle, the percent of energy provided by the home charger, the electric vehicle battery type that provides the battery capacity and efficiency, the charge rate of the EV charger, and the vehicle miles traveled per year. Units without an EV are also assigned a percent vehicle charge at home, an electric vehicle battery description, and a vehicle miles traveled so that they do not need to be sampled when applying an EV upgrade. While the charge rate is fixed in the model, the discharge rate is dynamically set using the miles traveled, vehicle efficiency, and a constant driving speed of 22 MPH (Federal Highway Administration 2017), which is then scaled at each timestep based on the ambient temperature using a curve derived from emprical data (Yip et al. 2023). Degredation of the battery over time is not considered. The schedules of charging and discharging are stochastic. The charging and discharging schedules are based on a single occupant in the dwelling unit assigned to the vehicle. Vehicle discharge events occur when the occupant leaves the unit and returns to the unit. The total duration of the discharging events is dependent on the annual vehicle miles traveled and the duration of individual events is proportional to the length of each away period. Charging is assumed to start when the occupant arrives back to the dwelling unit and the battery charges until a maximum state of charge is achived or the next trip occurs. Vacant units are not assigned an electric vehicle. The model draws data mainly from the TEMPO model, EIA RECS 2020 (U.S. Energy Information Administration 2020), the National Household Travel Survey (Federal Highway Administration 2017, 2022), registration data from Experian (Experian 2023), the No Place Like Home Study (Ge et al. 2021), and Autonomie model (Argonne National Laboratory 2025).

8.9.2 Electric Vehicle Characteristics

Electric Vehicle Ownership

Description

The dwelling unit owns an electric vehicle.

Distribution Data Source(s)

- EV Registration Data from Experian 2023.
- 2019-5yrs Public Use Microdata Samples (PUMS). IPUMS USA, University of Minnesota, www.ipums.org.
- U.S. EIA 2020 Residential Energy Consumption Survey (RECS) microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- PUMA
- Tenure

Options

The options for Electric Vehicle Ownership characteristic determine if other arguments for the EV are used. The characteristic sets the `vehicle_type` ResStock argument. The argument definition is found in Table 205.

Table 205. The ResStock argument definitions set in the Electric Vehicle Ownership characteristic

Name	Required	Units	Type	Choices	Description
`vehicle_type`	false		String		The type of vehicle present at the home.

The options and their ResStock arguments values can be found in Table 206. The Void option is used for impossible dependency conditions and is not sampled.

Table 206. Electric Vehicle Ownership options and arguments that vary for each option

Option name	`vehicle_type`
No	
Void	
Yes	BatteryElectricVehicle

Distribution Assumption(s)

- Due to low sample sizes, coarsening rules applied in the following order.
  1. Federal Poverty Level lumped every 100%
  2. Federal Poverty Level lumped every 200%
  3. Building type is consolidated into three bins 1) single-family, 2) multi-family, and 3) mobile home
  4. Building type is consolidated into two bins 1) single-family and 2) multi-family and mobile home
- PUMA level battery EV saturation is calculated using a weighted average of the County level Experian data and ResStock unit counts for each County and PUMA.
- The RECS 2020 satuations for each segment in a given PUMA are scaled to match the Experian PUMA weighted averaged battery EV saturation using the segment unit counts from PUMS 2019-5yrs survey.

Electric Vehicle Battery

Description

The type of electric vehicle and battery range in miles.

Distribution Data Source(s)

- The 2023 Vehicle Stock Projection Data from NREL's TEMPO model
- EV Registration Data from Experian 2023

Direct Conditional Dependencies

No direct conditional dependencies.

Options

The options for Electric Vehicle Battery characteristic is a set of electric vehicle types and battery range in miles. These options do not specifiy if the unit has a vehicle, but rather the preference of the vehicle type and battery range if the household owned an electric vehicle. Every unit is assigned one of these options so that the vehicle type and battery range does not need to be sampled during an electric vehicle upgrade. The housing units at which an electric vehicle is modeled are specified by the Electric Vehicle Ownership characteristic. The characteristic sets the `vehicle_battery_usable_capacity`, `vehicle_fuel_economy_units`, `vehicle_fuel_economy_combined`, `ev_average_mph`, and `ev_efficiency_percent_increase` ResStock arguments. The argument definitions are found in Table 207.

Table 207. The ResStock argument definitions set in the Electric Vehicle Battery characteristic

Name	Required	Units	Type	Choices	Description
`vehicle_battery_usable_capacity`	false	kWh	Double	auto	The usable capacity of the vehicle battery, only applies to electric vehicles. If not provided, the OS-HPXML default (see HPXML Vehicles) is used.

Table 207. The ResStock argument definitions set in the Electric Vehicle Battery characteristic (continued)

Name	Required	Units	Type	Choices	Description
`vehicle_fuel_economy_units`	false		Choice	auto, kWh/mile, mile/kWh, mpge, mpg	The combined fuel economy units of the vehicle. Only 'kWh/mile', 'mile/kWh', or 'mpge' are allow for electric vehicles. If not provided, the OS-HPXML default (see HPXML Vehicles) is used.
`vehicle_fuel_economy_combined`	false		Double	auto	The combined fuel economy of the vehicle. If not provided, the OS-HPXML default (see HPXML Vehicles) is used.
`ev_average_mph`	false	miles/hour	Double		The average miles/hour driven by the vehicle.
`ev_efficiency_percent_increase`	false	Frac	Double		The increase (fraction) in efficiency of the electric vehicle.

The options and their ResStock argument values can be found in Table 208. The Experian dataset is used to characterize the distribution of electric vehicles and associated battery sizes in the vehicle stock. We used the latest available data for the year 2023, which ensures that our analysis is based on the most current information regarding the electric vehicle battery stock. Although the vehicle data included information on internal combustion engine vehicles in addition to the battery electric vehicles, we filtered the dataset to focus exclusively on personal light-duty battery electric vehicles. In the dataset, there are four different categories of light-duty vehicles, including (a) Compact, (b) Midsize, (c) Sport Utility Vehicle (SUV), and (d) Pickup truck. Additionally, the dataset includes information on two total mileage ranges for the battery: (a) 200-mile range and (b) 300-mile range.

Then, for each electric vehicle type, we draw from Argonne National Laboratory's Autonomie20[9] vehicle powertrain simulation model for the electric vehicle energy consumption (`vehicle_fuel_economy_combined`) and battery capacity (`vehicle_battery_usable_capacity`). The units for the combined fuel economy (`vehicle_fuel_economy_units`) are always kWh/mile. The average driving speed is sourced from the 2017 NHTS which summarizes U.S. travel behavior (Federal Highway Administration 2017). We assume that the average speed of electric vehicles is the same as the average speed of all vehicles. A scaling factor is applied to increase the efficiency of electric vehicles (`ev_efficiency_percent_increase`). This value is 0.0 for the ResStock baseline meaning that the efficiency is equal to `vehicle_fuel_economy_combined`, but it is exposed so that scenarios of EV efficiency improvements can be modeled.

Table 208. Electric Vehicle Battery options and arguments that vary for each option

Option name	`vehicle_battery_usable_capacity`	`vehicle_fuel_economy_combined`	`ev_average_mph`	`vehicle_fuel_economy_units`	`ev_efficiency_percent_increase`
Compact, Battery Electric Vehicle, 200 mile range	40.168	0.209901	22	kWh/mile	0.0
Compact, Battery Electric Vehicle, 300 mile range	63.433	0.220020	22	kWh/mile	0.0
Midsize, Battery Electric Vehicle, 200 mile range	41.978	0.219174	22	kWh/mile	0.0
Midsize, Battery Electric Vehicle, 300 mile range	65.441	0.229449	22	kWh/mile	0.0

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[9] Autonomie is the source of TEMPO's inputs about electric vehicle characteristics for both current day and future scenarios

Table 208. Electric Vehicle Battery options and arguments that vary for each option

Option name	`vehicle_battery_usable_capacity`	`vehicle_fuel_economy_combined`	`ev_average_mph`	`vehicle_fuel_economy_units`	`ev_efficiency_percent_increase`
Pickup, Battery Electric Vehicle, 200 mile range	67.738	0.357648	22	kWh/mile	0.0
Pickup, Battery Electric Vehicle, 300 mile range	105.946	0.373794	22	kWh/mile	0.0
SUV, Battery Electric Vehicle, 200 mile range	53.503	0.267513	22	kWh/mile	0.0
SUV, Battery Electric Vehicle, 300 mile range	83.680	0.278934	22	kWh/mile	0.0

Distribution Assumption(s)

- Vehicle stock data starts with the Experian registration data and then is projected by TEMPO to 2023.
- If the household does not have an electric vehicle, the options represent the household preference.

Electric Vehicle Charge At Home

Description

The percentage a household would or does charge their electric vehicle at home.

Distribution Data Source(s)

U.S. EIA 2020 Residential Energy Consumption Survey (RECS) microdata.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS

Options

The options for the Electric Vehicle Charge At Home characteristic is a set of percentages that determine how much of the electric vehicle's energy shows up on the residential meter vs charging at work or at public chargers. Every unit in the baseline is assigned one of these options so that the home charging fraction does not need to be sampled during an electric vehicle upgrade. The units with an electric vehicle are specified by the Electric Vehicle Ownership characteristic. The characteristic sets the `vehicle_fraction_charged_home` ResStock argument. The argument definition is found in Table 209.

Table 209. The ResStock argument definitions set in the Electric Vehicle Charge At Home characteristic

Name	Required	Units	Type	Choices	Description
`vehicle_fraction_charged_home`	false		Double	auto	The fraction of charging energy provided by the at-home charger to the vehicle, only applies to electric vehicles. If not provided, the OS-HPXML default (see HPXML Vehicles) is used.

The options and their ResStock arguments values can be found in Table 210.

Table 210. Electric Vehicle Charge At Home options and arguments that vary for each option

Option name	`vehicle_fraction_charged_home`
0-19%	0.1
20-39%	0.3
40-59%	0.5
60-79%	0.7
80-99%	0.9
100%	1.0

Distribution Assumption(s)

- Due to a low sample count, the distributions are constructed by downscaling a dwelling unit sub-tsv with a household sub-tsv. The two sub-tsvs have the following dependencies: tsv1 dependency=['Geometry Building Type RECS'], tsv2 dependency=['Federal Poverty Level'], In combining tsv1 and tsv2, the conditional relationships are ignored across ('Geometry Building Type RECS' and 'Federal Poverty Level').

Electric Vehicle Charger

Description

Presence and type of electric vehicle charger used at the dwelling unit.

Distribution Data Source(s)

U.S. EIA 2020 Residential Energy Consumption Survey (RECS) microdata.

Direct Conditional Dependencies

- Electrical Vehicle Ownership
- Federal Poverty Level
- Geometry Building Type RECS
- Tenure

Options

The options for the Electric Vehicle Charger characteristic describe the type of charger used by an electric vehicle owner at home. The characteristic sets the `ev_charger_present`, `ev_charger_power`, and `ev_charger_location` ResStock arguments. The argument definition is found in Table 211. If `ev_charger_present` is set to "true", then the other arguments are required otherwise the power and location arguments will not be used. In the baseline stock the `ev_charger_location` argument is set to "auto", meaning it takes the default OpenStudio-HPXML value (see OpenStudio-HPXML Electric Vehicle Charger).

Table 211. The ResStock argument definitions set in the Electric Vehicle Charger characteristic

Name	Required	Units	Type	Choices	Description
`ev_charger_present`	false		Boolean	auto, true, false	Whether there is an electric vehicle charger present.
`ev_charger_power`	false	W	Double	auto	The rated power output of the EV charger. If not provided, the OS-HPXML default (see HPXML Electric Vehicle Chargers) is used.

Table 211. The ResStock argument definitions set in the Electric Vehicle Charger characteristic (continued)

Name	Required	Units	Type	Choices	Description
`ev_charger_location`	false		Choice	auto, garage, outside	The space type for the EV charger. If not provided, the OS-HPXML default (see HPXML Electric Vehicle Chargers) is used.

The options and their ResStock arguments values can be found in Table 212. The Void option will not be sampled but indicates when an impossible combination of dependencies are listed.

Table 212. Electric Vehicle Charger options and arguments that vary for each option

Option name	`ev_charger_present`	`ev_charger_power`	`ev_charger_location`
Level 1 charger	true	1600	auto
Level 2 charger	true	5690	auto
None	false		
Void	false		

Distribution Assumption(s)

Dwelling units with an electric vehicle need to have at least a Level 1 charger. Due to low sample sizes, coarsening of the dependencies are applied in the following order.

1. Federal Poverty Level lumped every 100%
2. Federal Poverty Level lumped every 200%
3. Building type is consolidated into three bins 1) single-family detached and 2) multi-family with 5+ units, and 3) mobile homes, multi-family 2-4 units, and single-family attached
4. Building type is consolidated into two bins 1) single-family detached and 2) all other building types
5. Federal Poverty Level is combined into 400%+ and <400% bins

Electric Vehicle Miles Traveled

Description

The number of miles an electric vehicle is driven in a year if the unit owns an electric vehicle.

Distribution Data Source(s)

The 2022 U.S. Federal Highway Administration National Household Travel Survey (NHTS) microdata.

Direct Conditional Dependencies

No direct conditional dependencies.

Options

The options for Electric Vehicle Miles Traveled characteristic are a set of miles traveled by the electric vehicle. These options do not specifiy if the unit has a vehicle, but rather the amount of miles the EV travels if the dwelling unit has an electric vehicle. Every unit is assigned one of these options so that the vehicle miles traveled does not need to be sampled during an electric vehicle upgrade. The units with an electric vehicle is specified by the Electric Vehicle Ownership characteristic. The characteristic sets the `vehicle_miles_driven_per_year` ResStock argument. The argument definition is found in Table 213.

Table 213. The ResStock argument definitions set in the Electric Vehicle Miles Traveled characteristic

Name	Required	Units	Type	Choices	Description
`vehicle_miles_driven_per_year`	false	miles	Double	auto	The annual miles the vehicle is driven. If not provided, the OS-HPXML default (see HPXML Vehicles) is used.

The options and their ResStock arguments values can be found in Table 214. The options range between 1,000 miles and 22,500 miles.

Table 214. Electric Vehicle Vehicle Miles Traveled options and arguments that vary for each option

Option name	`vehicle_miles_driven_per_year`
1000	1000
3000	3000
5000	5000
7000	7000
9000	9000
11000	11000
13000	13000
15000	15000
17000	17000
19000	19000
22500	22500

Distribution Assumption(s)

No assumptions are made.

Electric Vehicle Outlet Access

Description

The unit has an outlet within 20 feet of vehicle parking.

Distribution Data Source(s)

U.S. EIA 2020 Residential Energy Consumption Survey (RECS) microdata.

Direct Conditional Dependencies

- Electric Vehicle Charger
- Federal Poverty Level
- Geometry Building Type RECS
- Tenure
- Vinteage ACS

Options

The options for Electric Vehicle Outlet Access characteristic indicate whether the unit has charging within 20 ft of the vehicle parking. This characteristic does not assign any ResStock arguments. The options are Yes, No, and Void. The Void option is assigned to impossible dependency combinations.

Distribution Assumption(s)

- RECS 2020 has Multi-Family 5+ units marked as Not Applicable. These units are replaced by data from the No Place Like Home Study (https://www.nrel.gov/docs/fy22osti/81065.pdf) Table 1 Scenario 2. Multi-Family 5+ units owners is assumed for 12% units having electrical access. This fraction is based on the average of mid-capacity apartment and high-capacity apartment. Multi-Family 5+ units owners is assumed for 28% units having electrical access.
- Units reported to have a Level 1 or Level 2 charger in the field EVCHRGTYPE are assumed to have outlet access.
- Level 1 chargers without outlet access are units with EVs, but report no outlet access within 20 ft of vehicle parking.
- Due to low sample count, the tsv is constructed by downscaling a dwelling unit sub-tsv with a household sub-tsv. The sub-tsvs have the following dependencies:
  - Dwelling unit sub-tsv : deps=['Geometry Building Type RECS', 'Vintage ACS', 'Electric Vehicle Charger'] with the following fallback coarsening order: 1) Vintage ACS to the National distribution and 2) combining Geometry Building Type RECS together into two bins a) single-family detached, mobile homes, and single family attached and b) multi-family with 2 - 4 units and multi-family with 5+ units
  - Household sub-tsv : deps=['Geometry Building Type RECS', 'State' 'Tenure', 'Federal Poverty Level']
  - In combining the dwelling unit sub-tsv and household sub-tsv, the conditional relationships are ignored across (['Vintage ACS', 'Electric Vehicle Charger'], ['Tenure', 'Federal Poverty Level']).

8.9.3 Electric Vehicle Charging and Discharging Schedules

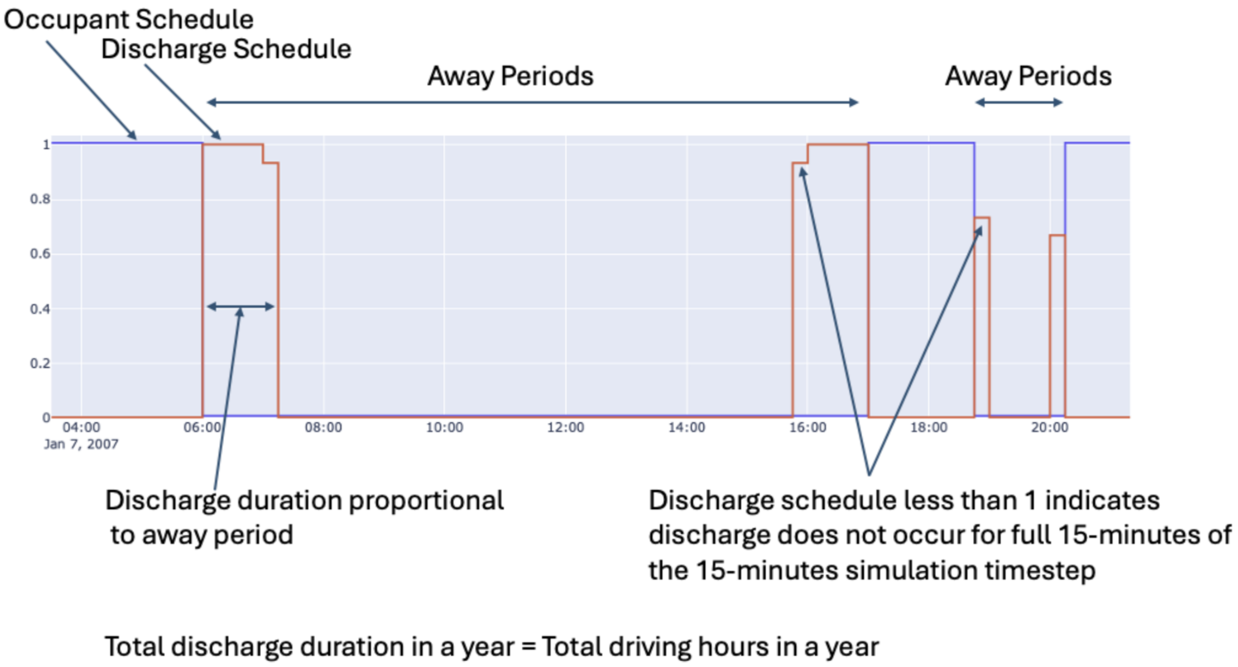
Charging and discharging schedules provide the time periods when the EV can charge or discharge energy. The charging and discharging schedules are connected to the stochastic occupancy model (based on American Time Use Survey data) in OpenStudio-HPXML. Each unit with an EV has an occupant assigned as the sole driver. The schedule generator takes EV vehicle miles traveled and the average speed to calculate the total hours driven per year. The total hours driven per year is used as an input to the EV schedule generator and produces the charging and discharging schedule, while the battery model takes care of the actual power draw during the charging and discharging period. Figure 14 shows an example of a generated discharging schedule. This schedule shows that during an “away period” for the occupant, the vehicle is discharged immediately after the occupant leaves and just before they arrive back home, proportional to the length of the away period. The charging schedule is similarly based on occupancy, where the baseline behavior assumes the vehicle is plugged in when the occupant arrives home, and remains plugged in for the full occupied period. EV schedules are not generated for vacant units and EV charging loads are not modeled.

8.10 Electrical Panels

The electrical panel is a breaker box that distributes power from the utility pole to the connected appliances and receptacles while protecting them from overload, short circuit, or ground fault. Inside the panel, electric appliances are organized into branch circuits that are each protected by an overcurrent protection device (A.K.A. breaker). Two bus bars each carrying 120V service along with a neutral bus bar run down the breaker slots to supply power at either 120V or 240V. 120V circuits use single-pole breakers that take up one space while 240V require two-space double-pole breakers to draw the 240V potential between the two hot wires. Some breakers, such as tandem breakers, can serve multiple circuits without taking up more space. The panel service rating refers to the maximum amps of current the panel can safely handle to power the circuits. This is often the same as the ampacity rating of the service entrance disconnect, which limits the amount of power entering the panel, though it is possible to have a panel rated larger than its service disconnect, and vice versa.

8.10.1 Overview

The electrical panel service load and breaker space calculations are used to assess whether the electrical panel has a capacity and a space constraint, respectively, during a home electrification. As new electric loads are introduced into



Discharge duration proportional to away period

Discharge schedule less than 1 indicates discharge does not occur for full 15-minutes of the 15-minutes simulation timestep

Total discharge duration in a year = Total driving hours in a year

Figure 14. Illustration of EV battery discharge schedule generation.

the home, the panel may need to be reconfigured, extended, or replaced due to insufficient capacity or insufficient breaker space. For example, homes that are not already using electricity for heating and cooking are more likely to have capacity constraints, thus requiring an upgrade, load controls, or other interventions. A panel with all slots occupied cannot accommodate new circuits unless space-saving breakers are used, or a subpanel is added. When the panel is being upsized for capacity, an electrical service upgrade may also be required to upsize the service entrance wiring from the pole to the service disconnect. By estimating the panel capacity constraints, the service load calculation can serve as an upper bound estimate for service upgrades when applied to the housing stock.

To evaluate potential panel constraints, we first characterize the panel service rating and the number of available breaker spaces on the panels for the US housing stock using best available data. Then we perform service load calculations based on code to get the required capacity for a given upgrade scenario. The calculated value is compared with the rating of the panel to determine the capacity constraint. For the breaker space calculation, the number of occupied breaker spaces on the panel is estimated by tabulating from each appliance for a given modeled home. This pre-upgrade occupied space estimate is combined with the available breaker space input to determine the rated total number of spaces on the panel. Then the number of occupied breaker spaces is calculated for the modeled home post-upgrade and subtracted from the rated number of spaces to determine the space constraint for a given upgrade scenario. The following sections provide more detail on each of the two calculations. The electrical panel outputs can be found in Section 9.8.

8.10.2 Input Characteristics

We derived the electrical panel service rating (A) and the breaker space headroom using a limited set of survey data. For single-family attached and detached dwellings, the data was used to train machine-learning models, which were then used to generate the distribution of the panel attributes. For multi-family, the characteristic distributions were derived directly from the data due to insufficient samples to support model training. As the dataset does not contain high-fidelity samples for mobile homes, we use the distributions for single-family detached to approximate mobile homes.

79% of the survey data comes from the Pacific regions via: TECH Clean California, Bay Area Renewable Energy Network, Home Energy Analytics, and Northwest Energy Efficiency Alliance Residential Building Stock Assessment, while 20% comes from the Minnesota Center for Energy and the Environment and 1% from LBL Citizen Science survey, which is administered nationally. Due to the data bias towards the Pacific states, where gas heating is dominant, separate model is used for electrically heated and fuel heated single-family dwellings. Table 215 outlines the dependencies for each of the distributions generated for assigning the panel characteristics. Major electric load count include space heating, central cooling, water heating, drying, cooking, solar PV, and electric vehicle charging. The field values for electrical panel service rating (A) are: <100, 100, 101-124, 125, 126-199, 200, 201+. The availale breaker space options (count) range from 0 to 31.

Table 215. Dependencies for the distributions of electrical panel service rating and breaker space.

Electrical Panel Input	Housing Segment	Dependencies
Service rating	Single-Family, electric heat	Building type, floor area, vintage, water heater fuel, cooling type, clothes dryer, cooking range
Service rating	Single-Family, fuel heat	Building type, floor area, vintage
Service rating	Multi-Family	Floor area, vintage, heating fuel
Breaker space headroom	Single-Family	Service rating, major electric load count, floor area
Breaker space headroom	Multi-Family	Service rating, major electric load count

8.10.3 Service Load Calculations

The service and feeder load calculation refers to a type of load calculation used to size the service entrance wires (between the utility poles and the meter or service disconnect) or the feeder wires (between panels, such as those between a building's main panel and subpanel in each apartment unit) according to Section 220 of the National Electrical Code (NEC). This calculation also applies to the sizing of panels to ensure electrical safety. The NEC updates every three years, and the adoption of NEC varies by municipality. Instead of capturing every NEC version currently in practice, which is impractical, we implemented the load calculations per the latest NEC release, 2023, which represents the best practice adoptable. For 2023, the service load calculation is different for new constructions and existing buildings undergoing an upgrade. Two methods are available for existing buildings, and both are implemented in ResStock: load-based and metered-based. The calculated loads (W) represent the total occueied load from installed electrical equipment and are converted to total occupied capacity (A) by dividing by 240V, the panel voltage. The occupied capacity is compared with the panel service rating to calculate headroom capacity and assess NEC compliance.

Load-based Method

The service rating of the panel is generally not the sum of individual branch circuit ratings because not all equipment is expected to be operating at full load simultaneously. Instead, there is some diversity in the loads expected to make up the coincidence peak, even at a worst-case scenario. Following this idea, NEC Section 220.83 provides guidance on estimating this peak from the bottom-up to assess whether a panel has sufficient capacity to serve new loads. Table 216 below summarizes the load-based method, and the assumptions made in ResStock to perform this calculation.

Table 216. Summary of load-based method per 2023 NEC 220.83

Load Type	Load Amount	ResStock Assumptions
General lighting / receptacle load	3 W/sqft	Uses conditioned floor area
Kitchen small appliance circuits	Min two branches at 1500 W each	Two branches per dwelling unit
Laundry circuits	Min one branch at 1500 W	One branch per dwelling unit

Table 216. Summary of load-based method per 2023 NEC 220.83 (continued)

Load Type	Load Amount	ResStock Assumptions
Major electric loads	Nameplate rating of: • HVAC (larger of heating and cooling) • Water heaters • Clothes dryers (not already on laundry circuits) • Cooking ranges/ovens • All other appliances that are "fastened in place, permanently connected, or located to be on a specific circuit"	All other appliances include: • Hot tub/spa • Pool heaters and pumps • Well pumps • Electric vehicle supply equipment (EVSE) • Dishwashers • Spot ventilations • Selected plug loads: microwaves, garbage disposal, garage doors • Low-power (120V) appliances: water heaters, cooktops (not yet modeled)
Demand factors and summation	Demand factors apply to both existing and new loads, depends on whether new HVAC is being installed: • (a) If not adding new HVAC, take the first 8 kVA of all loads at 100% and remainder loads at 40%. • (b) If adding new HVAC, take HVAC load at 100%, first 8 kVA of all other loads at 100%, and remainder loads at 40%.	Total occupied capacity in the baseline is calculated using (a)

Of note, we accounted for selected plug loads in the load-based calculation that we do not explicitly model in terms of energy for which plug loads is a single end use category. We assumed all dwelling units have a microwave, 52% homes have a garage disposal (per AHS 2013), and one garage door opener for homes with an attached garage. Additionally, the demand factors applied to sum up the loads vary depending on whether new HVAC load is being introduced by an upgrade. If all or part of the HVAC load is considered new, a more conservative approach (part (b)) is taken by taking the HVAC load (maximum of either heating or cooling) at 100% instead of lumping it with all other loads to undergo adjustment by demand tiers. For the baseline load calculation, the total occupied load is calculated using part (a) as no new load is introduced yet.

Meter-based Method

The second method, metered-based, is a top-down approach by using the metered electricity peak of the preceding year to baseline the existing loading of the panel. Per NEC section 220.87, the total capacity needed for an upgrade is calculated as 1.25 of the baseline peak electricity plus any new loads at 100%. In ResStock, the annual electricity peak is used in place of the metered data and the new loads that are counted are the same as those outlined in the load-based method.

For a given upgrade, the load-based method is generally more conservative than the metered-based at estimating the number of homes with a panel capacity constraint. However, this may not be the case for homes that have high equipment utilization factors or setpoints that drive up HVAC use. Additionally, as the metered-based method does not account for the removal of any legacy loads, the method may be more conservative for certain upgrade scenarios. For example, for a home that is upgrading an electric boiler to a heat pump with integrated heat strip, the heating load is being counted twice, from the incumbent equipment as part of the annual electric peak and the new equipment.

Space Heating and Cooling Loads

The load for space heating and cooling is determined separately and only the larger of the two is used in the load calculation. The power rating of the system is the sum of its individual components, which are summarized in Table 217. For example, the power rating of a ducted heat pump is the sum of the power rating of the compressor, the air handler, and any electric backup that can operate simutaneously as the heat pump. If only the heat pump or the backup is allowed at a given time, ResStock takes only the maxium of the heat pump or the backup rating. This also applies to non-ducted heat pumps, whose power rating can be estimated based on compressor and any applicable electric backup.

The compressor power rating is estimated based on its design capacity using a regression equation derived from a review of over 200 direct expansion systems. The products reviewed include ducted and non-ducted air source heat pumps, central AC, and 240V room AC, as a similar trend is observed across them. The regression estimates the Minimum Circuit Amp of the compressor, which is then multiplied by the voltage (240V) to arrive at power. This regression is also being applied to ground source heat pumps, as ground source heat pump specific product information is not yet surveyed. The electric resistance heating power rating is directly converted from its design heating capacity at an efficiency of 100%. The air handler and boiler pump power ratings are estimated from their respective OS-HPXML modeling assumptions. For fuel heating systems, their service rating only consists of their auxiliary equipment.

Table 217. Default service rating of space heating and cooling system components.

System Component	Power Rating [W]	Note
Heat Pump or AC Compressor	(0.631 * Heating_or_Cooling_Capacity [kBtu/h] + 1.615) * 240	Regression of Minimum Circuit Amp, multiplied by voltage. Applies to ground source heat pumps.
Electric Resistance Furnace, Boiler, or Strip Heat	Heating_Capacity [kBtu/h] * 293.07	Convert heating capacity to power directly at 100% efficiency
Air Handler	Air_Flow [cfm] * Fan_Power [W/cfm]	Default to OS-HPXML blower fan assumptions
Boiler Pump	Boiler_Auxiliary_Energy [kWh/yr] / 2.08	Default to OS-HPXML boiler pump assumptions

8.10.4 Breaker Space Calculations

The breaker space calculation is broken out into two parts. First the total rated breaker space is determined for the panel in the baseline home. This is done by summing the number of available breaker spaces (probabilistically assigned based on housing characteristics) and the estimated total occupied spaces by major electric equipment. Table 218 below lists the electric equipment considered and their associated voltage and breaker space requirement. Generally 120V-rated equipment take up one breaker space and 240V-rated equipment take up two spaces in order to make contact with two live bus bars to get the 240V service. While space-saving breakers, such as tandem, tri, and quad breakers, are available, they are not currently modeled in ResStock.

Table 218. Default voltage and breaker space by load type.

Load Name	Voltage	Breaker Spaces	Notes
lighting	120	2	
kitchen	120	2	Two kitchen small appliance circuits.
laundry	120	1	One laundry circuit.
electric vehicle charging	120	1	Level 1 - 120V EV charger. Assumes dedicated circuit.
electric vehicle charging	240	2	Level 2 - 240V EV charger.
well pump	240	2	
pool pump	240	2	2 HP pool pump capacity.

Table 218. Default voltage and breaker space by load type. (continued)

Load Name	Voltage	Breaker Spaces	Notes
pool heater	240	6	Electric resistance pool heater. Three 50A circuit breaker.
pool heater	240	2	Heat pump pool heater.
permanent spa heater	240	2	Electric resistance hot tub heater.
permanent spa heater	240	2	Heat pump hot tub heater.
permanent spa pump	240	2	Hot tub pump.
clothes dryer	240	2	Electric clothes dryer.
clothes dryer	120	1	120V heat pump clothes dryer.
clothes dryer	240	2	240V heat pump clothes dryer.
dishwasher	120	1	Dishwasher.
range/oven	120	1	120V range-oven.
range/oven	240	2	240V range-oven.
hot water	240	4	Tankless water heater - one bathroom. The default power rating is 1800W. Two 50A circuit breaker.
hot water	240	4	Tankless water heater - two bathrooms. The default power rating is 2400W. Two 50A circuit breaker.
hot water	240	6	Tankless water heater - three or more bathrooms. The default power rating is 3600W. Three 50A circuit breaker.
hot water	240	auto	Storage water heater. The default power rating is auto sized. The number of breaker space = 2 * round_up(power rating [W] / 240V / 50A).
hot water	120	auto	120V heat pump water heater. Assumes dedicated circuit. The default power rating is auto sized. The number of breaker space = round_up(power rating [W] / 240V / 15A).
hot water	240	auto	240V heat pump water heater. The default power rating is auto sized. The number of breaker space = 2 * round_up(power rating [W] / 240V / 50A).
heating	240	auto	The default power rating is auto sized and includes auxiliary devices such as air handler and hydronic pump. The number of breaker space depends on the HVAC configuration, but generally = 2 * round_up(power rating [W] / 240V / 50A).
cooling	240	auto	The default power rating is auto sized and includes auxiliary devices such as air handler and hydronic pump. The number of breaker space depends on the HVAC configuration, but generally = 2 * round_up(power rating [W] / 240V / 50A).
mechanical ventilation	120	1	
other	120	1	Only assumes 1 garage door opener if a garage is present and does not account for other permanent appliances (e.g. garbage disposal).

Determining the breaker space requirement for heat pump is a bit complicated - it depends on whether the system is ducted, dual-fuel, or has backup, and ultimately how the subsystems are electrically configured. For ducted systems, for example, the indoor unit (IDU, or air handler) and the outdoor unit (ODU, or compressor) can be on the same circuit (with a disconnect switch) or they can be on separate circuits, in which case, more spaces are required. The air handler is typically 240V to allow for the installation of heat strip backup on the same circuit, in which case, the

ODU must be on a second circuit. For dual-fuel systems, the air handler can be 120V. Table 219 below summarizes the breaker space requirement implemented in ResStock.

Table 219. Default voltage and breaker space by heat pump systems. (Note: ckt = circuit)

Heat Pump System	Circuits	Breaker Spaces
Air-to-air, ducted, dual-fuel	ckt 1: 240V, ODU ckt 2: 120V, IDU	ckt 1: 2 * round_up(ODU power [W] / 240V / 50A) ckt 2: 1
Air-to-air, ducted, no backup	ckt 1: 240V, ODU ckt 2: 240V, IDU	ckt 1: 2 * round_up(ODU power [W] / 240V / 50A) ckt 2: 2
Air-to-air / mini-split, ducted, electric backup	ckt 1: 240V, ODU ckt 2: 240V, IDU + backup	ckt 1: 2 * round_up(ODU power [W] / 240V / 50A) ckt 2: 2 * round_up((IDU + backup) power [W] / 240V / 50A)
Mini-split, ductless, fuel backup	ckt 1: 240V, ODU ckt 2: depends on fuel heating	ckt 1: 2 * round_up(ODU power [W] / 240V / 50A) ckt 2: depends on fuel heating
Mini-split, ductless, no backup	ckt 1: 240V, ODU	ckt 1: 2 * round_up(ODU power [W] / 240V / 50A)
Mini-split, ductless, electric backup	ckt 1: 240V, ODU ckt 2: 240V, backup	ckt 1: 2 * round_up(ODU power [W] / 240V / 50A) ckt 2: 2 * round_up(backup power [W] / 240V / 50A)
Mini-split, ducted, no backup	ckt 1: 240V, ODU + IDU	ckt 1: 2 * round_up((ODU + IDU) power [W] / 240V / 50A)

Once the total rated breaker space is calculated, it is used to calculate the headroom breaker space in an upgrade simulation by subtracting from it the new total spaces occupied by electric loads in the upgraded home. Note, although the headroom breaker space for the baseline is an input characteristic, all space-related metrics are listed as output metrics to avoid confusion.

8.11 Household Characteristics

In addition to the physical characteristics of the housing units, ResStock defines the saturation of some attributes of the households. They are income and derivatives of income, tenure (renter/owner status), occupants, presence of Tribal persons, and vacancy status. All household attributes come from the 2019 5-year American Community Survey (ACS) Public Use Microdata Samples. The ACS is the premier census data source on the American population in addition to housing information. The survey collects data on all residents of sampled housing unit addresses. This means housing data such as building type and vacancy are tabulated by *household_id*, while population attributes such as age, race, and gender are tabulated by *person_id*. The ACS is also used to develop DOE's Low-Income Energy Affordability Data tool.

8.11.1 Income

The ACS reports both household and family incomes in continuous values, which are then binned in ResStock. Income in ResStock represents the household income, or the total income of all household members age 15 or higher standardized to 2019 dollars. From income a variety of secondary income parameters are derived. Income RECS2015 and Income RECS2020 are binned variations that align with the reported bins from RECS 2015 and 2020, respectively. Federal poverty level (FPL) standardizes the household income according to the 2019 U.S. federal poverty guidelines, which vary based on household size and differ for the contiguous United States, Hawaii, and Alaska. Table 220 shows the poverty lines by household size for the lower 48 states including D.C., for Hawaii, and for Alaska.

Per Table 220, the poverty line is $25,750 for a household of four in the contiguous U.S. A household of the same size making $40,000 per year in Colorado is therefore at 150%–200% of FPL (40,000/25,750*100% = 155%). However, that exact household would be considered 100%–150% of FPL if living in Hawaii instead (40,000/29,620*100% = 135%). FPL is used to determine eligibility for several federal assistance programs, including Low-Income Home

Table 220. 2019 federal poverty guidelines (Assistant Secretary For Planning and Evaluation, n.d.(a))

Household size	Contiguous U.S.	Hawaii	Alaska
1	$12,490	$14,380	$15,600
2	$16,910	$19,460	$21,130
3	$21,330	$24,540	$26,660
4	$25,750	$29,620	$32,190
5	$30,170	$34,700	$37,720
6	$34,590	$39,780	$43,250
7	$39,010	$44,860	$48,780
8	$43,430	$49,940	$54,310
Per additional person over 8	$4,420	$5,080	$5,530

Energy Assistance Program (LIHEAP) and Weatherization Assistance for Low-Income Persons (Assistant Secretary For Planning and Evaluation, n.d.(b)).

Similar to FPL, Area Median Income in ResStock is household income standardized as a percentage of the 2019 Income Limits, which are annually updated by HUD. The Income Limits are means-testing metrics intended to determine financial assistance eligibility, such as Section 8 housing, based on family income (Department of Housing and Urban Development 2019). Since ResStock does not model multiple families sharing a single housing unit, household income is treated the same as family income, and household income is used to calculate percent Area Median Income instead. Like FPL, the income limits vary by family size. But unlike FPL, they adjust for local housing costs and vary by county subdivisions. Generally, 0%–80% Area Median Income is regarded as Low-to-Moderate Income and the threshold for receiving most types of financial assistance. Sometimes 80%–150% Area Median Income households are eligible for partial financial assistance, such as in Section 50122 of the Inflation Reduction Act (U.S. Congress 2022) for home electrification rebates.

State Metro Median Income (SMMI) is a variant of Area Median Income. As the name suggests, SMMI standardizes the household income based on 2019 Income Limits set at the state level while differentiating between metropolitan and non-metropolitan areas. This metric is created primarily for the integration of socio-demographically differentiated time-use schedules from the American Time Use Survey, which tags respondents by state and metro status.

8.11.2 Energy Burden

Energy burden can be calculated using the energy bills and income information from ResStock simulation summary results. Energy burden is defined as the percent of household income spent on energy bills. A household spending 6% or more of their income on energy is generally regarded as highly energy burdened and 10% or more as severely burdened (Drehobl, Ross, and Ayala 2020). For this calculation, the income bins can be converted to representative income values using a series of lookup tables derived from the ACS data. The lookup tables tabulate the weighted median income over the cross sections of income bin, occupants, FPL, tenure, building type, and different geographic resolutions, starting with the intersection of PUMA and county. The income bin gets converted to a numerical value for each housing sample by matching the mapping 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 is missing until all housing samples are converted.

8.11.3 Vacant Units

ResStock models just over 12% of housing units as vacant nationally, reflecting the data in PUMS 2019. In PUMS, a housing unit is considered vacant if it is not occupied at the time of the survey. This includes housing units being prepared for rent or sale, units rented or sold but not yet occupied, or units for seasonal, occasional, or migratory use. The portion of housing units that are vacant is dependent on the building type and PUMA (i.e., location). While the vacancy saturation includes samples that are only vacant part time, ResStock models all vacant units as vacant for an entire calendar year.

In most cases ResStock models vacant units using the same characteristic distributions as occupied units. For example, RECS, where all of the respondents are unit occupants, does not have unoccupied units included in its survey. Tenure is a dependency in many of the appliance characteristics derived from RECS. In those characteristics distributions, Tenure=Not Available is analogous to vacant units and their distributions are based on the full dataset (i.e., the occupied units regardless of tenure). The distribution of Geometry Floor Area, however, which comes from 2017–2019 American Housing Survey, has a real distinction between renter-occupied, owner-occupied, and vacant units, as the survey records both tenure and vacancy information.

The differences between our modeling of occupied units and vacant units are currently confined to these areas: heating setpoint, schedule-driven loads and ceiling fans, PV, and demographics.

Vacant units are set to have a heating setpoint characteristic of 55°F, intended as a "don't freeze the pipes" approach. Vacancy status is not in the dependency tree for the heating setpoint offset characteristics, so many vacant housing units are modeled with heating setpoint offsets from that 55°F.

Reflecting a lack of occupants, vacant units are modeled without any schedule-driven appliance usage. This results in no energy consumption for the following end uses across all fuels:

- Ceiling fan (albeit through a different mechanism)
- Clothes dryer
- Clothes washer
- Dishwasher
- Fireplace
- Grill
- Lighting (all types)
- Mechanical ventilation
- Well pump
- Plug loads
- Range/oven
- TVs.

There are also no PV systems modeled for vacant units. Because vacant units have no associated household—no set of people that live in them—their *occupants* characteristic is 0 and they do not have household-based characteristics such as *income* or *tenure*. All other characteristics, modeling approaches, and end uses are independent of vacancy status; that is, if the housing unit had the same characteristics and was occupied, it would have the same results.

8.11.4 Other Household Attributes

Occupants is the household size or the number of residents living together in a housing unit. Occupant is zero for vacant units and 10+ is modeled as 11. This assumption is used when converting household income to FPL, Area Median Income, or SMMI. Tenure defines whether a housing unit is renter- or owner-occupied. A unit occupied without rent payment is considered renter-occupied under the assumption that the occupants cannot easily update the property without the ownership. "Household Has Tribal Persons" is derived from the person samples to indicate whether a household has at least one person identified as American Indian or from one of the American Tribes. These household characteristics are either zero or not available for vacant units.

The details of each household characteristics are found in the next section.

Income

Description

Income of the household occupying the housing unit.

Distribution Data Sources

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Geometry Building Type RECS
- PUMA
- Tenure
- Vintage ACS.

Options

The Income options are a set of income bins ranging from 10,000 to 199,999. The two end bins are <10,000 and 200,000+. This characteristic has no ResStock arguments. Instead, it is used to construct other income characteristics and influences the distribution of housing characteristics as an indirect dependency.

Distribution Assumptions

- In ACS, Income and Tenure are reported for occupied units only. Because we assume vacant units share the same Tenure distribution as occupied units, by extension, we assume this Income distribution applies to all units regardless of Vacancy Status. For reference, 57445 / 140160 rows have sampling_probability >= 1/550,000.[10] Of those rows, 2961 (5%) were replaced due to low samples in the following process: Where sample counts are less than 10 (79145 / 140160 relevant rows), the Census Division by PUMA Metro Status average distribution has been inserted first (76864), followed by Census Division by 'Metro'/'Non-metro' average distribution (1187), followed by Census Region by PUMA Metro Status average distribution (282), followed by Census Region by 'Metro'/'Non-metro' average distribution (112).

Income RECS2015

Description

Income of the household occupying the housing unit that are aligned with the 2015 U.S. Energy Information Administration Residential Energy Consumption Survey.

Distribution Data Sources

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Income.

Options

The Income RECS2015 option are bins mapped from the Income characteristic to align with the RECS 2015 income bins. The characteristic does not set any ResStock arguments.

Distribution Assumptions

- The income in 2019 USD are consolidated to align with those of RECS 2015 without inflation adjustment.

Income RECS2020

Description

Income of the household occupying the housing unit that are aligned with the 2020 U.S. Energy Information Administration Residential Energy Consumption Survey.

Distribution Data Sources

- 2019 5-year PUMS from the University of Minnesota.

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[10] 550,000 is the typical sample size for ResStock, indicating that these rows are likely to get sampled.

Direct Conditional Dependencies

- Income.

Options

The Income RECS2020 options are bins mapped from the Income characteristic to align with the RECS 2020 income bins. The characteristic does not set any ResStock arguments.

Distribution Assumptions

- The income in 2019 USD are consolidated to align with those of RECS 2020 without inflation adjustment.

Federal Poverty Level

Description

Income as a percent of the federal poverty line of the household occupying the housing unit.

Distribution Data Sources

- Income from 2019 5-year PUMS from the University of Minnesota.
- 2019 federal poverty guidelines from Office of the Assistant Secretary for Planning and Evaluation within the U.S. Department of Health and Human Services.

Direct Conditional Dependencies

- Income
- Occupants.

Options

The Federal Poverty Level options are the following bins: %0–100%, 100%–150%, 150%–200%, 200%–300%, 300%–400%, and 400%+. The Not Available option is for vacant units. The Federal Poverty Level options do not set any ResStock arguments.

Distribution Assumptions

- Percent Federal Poverty Level is calculated using annual household income in 2019 USD (continuous, not binned) from 2019 5-year PUMS data and 2019 Federal Poverty Lines for contiguous U.S., where the FPL threshold for 1-occupant household is $12,490 and $4,420 for every additional person in the household.

Area Median Income

Description

Income as a percent of area median income of the household occupying the housing unit.

Distribution Data Sources

- Income from 2019 5-year PUMS from the University of Minnesota.
- Area Median Income definitions based on 2019 Income Limits from HUD.

Direct Conditional Dependencies

- Income
- Occupants
- PUMA.

Options

The Area Median Income options are the following bins: 0%–30%, 30%–60%, 60%–80%, 80%–100%, 100%–120%, 120%–150%, and 150+%. The Not Available option is for vacant units. The Area Median Income options do not set any ResStock arguments.

Distribution Assumptions

1. Percent Area Median Income is calculated using annual household income in 2019 USD (continuous, not binned) from 2019 5-year PUMS data and 2019 income limits from HUD. These limits adjust for household size AND local housing costs (i.e., fair market rents). Income limits reported at county subdivisions are consolidated to County using a crosswalk generated from Missouri Census Data Center's geocorr (2014), which has 2010 ACS housing unit count.
2. For the 478 counties available in PUMS (60%), the county-level income limits are used. For all others (40%), PUMA-level income limits are used, which are converted from county-level using 2010 ACS housing unit count.

State Metro Median Income

Description

State Metro Median Income of the household occupying the housing unit. This is different from State Median Income in that the Income Limits are differentiated by metro and nonmetro regions of the state.

Distribution Data Sources

- Income from 2019 5-year PUMS from the University of Minnesota.
- Income Limits derived from 2019 5-year PUMS from the University of Minnesota and 2019 median income by state and metro/nonmetro area from HUD.

Direct Conditional Dependencies

- Area Median Income
- County Metro Status
- State.

Options

The State Metro Median Income options are the following bins: 0%–30%, 30%–60%, 60%–80%, 80%–100%, 100%–120%, 120%–150%, and 150+%. The Not Available option is for vacant units. The State Metro Median Income options do not set any ResStock arguments.

Distribution Assumptions

- Percent State Metro Median Income is calculated using annual household income in 2019 USD (continuous, not binned) from 2019 5-year PUMS data and 2019 median income by state and metro/nonmetro area from HUD. A County Metro Status-differentiated Income Limits table is derived from the median income table by adjusting for household size, which is consistent with the method of generating state income limits by HUD.

Occupants

Description

The number of occupants living in the housing unit.

Distribution Data Sources

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Bedrooms
- Census Division
- Geometry Building Type RECS
- Income RECS2015
- PUMA Metro Status
- Tenure.

Options

The Occupants options range from 0 to 10+ for the the ResStock baseline baseline (Table 221). This characteristic assigns value to `geometry_unit_num_occupants` accordingly, with `geometry_unit_num_occupants`=11 for Occupants=10+. Occupants=0 corresponds to vacant units. `general_water_use_usage_multiplier` is auto-calculated from occupants.

Table 221. The ResStock arguments set in the Occupants characteristic

Name	Required	Units	Type	Choices	Description
`geometry_unit_num_occupants`	false	#	Double		The number of occupants in the unit. If not provided, an *asset* calculation is performed assuming standard occupancy, in which various end-use defaults (e.g., plug loads, appliances, and hot water usage) are calculated based on Number of Bedrooms and Conditioned Floor Area per ANSI/RESNET/ICC 301-2019. If provided, an *operational* calculation is instead performed in which the end-use defaults are adjusted using the relationship between Number of Bedrooms and Number of Occupants from RECS 2015.
`general_water_use_usage_multiplier`	false		Double	auto	Multiplier on internal gains from general water use (floor mopping, shower evaporation, water films on showers, tubs & sinks surfaces, plant watering, etc.) that can reflect, e.g., high/low usage occupants.

Distribution Assumptions

- Option=10+ has a (weighted) representative value of 11. In ACS, Income, Tenure, and Occupants are reported for occupied units only. Because we assume vacant units share the same Income and Tenure distributions as occupied units, by extension, we assume this Occupants distribution applies to all units regardless of Vacancy Status. Where sample counts are less than 10 (6,243 / 18,000 rows), the Census Region average distribution has been inserted first (2,593), followed by national average distribution (2,678), followed by national + ‘MF’/‘SF’ average distribution (252), followed by national + ‘MF’/‘SF’ + ‘Metro’/‘Non-metro’ average distribution (315), followed by national + ‘MF’/‘SF’ + ‘Metro’/‘Non-metro’ + Vacancy Status average distribution (657).

Vacancy Status

Description

The vacancy status (occupied or vacant) of the housing unit.

Distribution Data Sources

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Geometry Building Type RECS
- PUMA.

Options

The Vacancy Status options are either Occupied or Vacant. The options assign the vacancy periods through the `schedules_vacancy_periods` ResStock argument (Table 222). Vacant units are assumed to be vacant for the full calendar year.

Table 222. The ResStock arguments set in the Vacancy Status characteristic

Option name	`schedules_vacancy_periods`
Occupied	
Vacant	Jan 1–Dec 31

The argument definition of the arguments set in the Vacancy Status characteristic can be found in Table 223.

Table 223. The ResStock arguments set in the Vacancy Status characteristic

Name	Required	Units	Type	Choices	Description
`schedules_vacancy_periods`	false		String		Specifies the vacancy periods. Enter a date like “Dec 15–Jan 15.” Optionally, can enter hour of the day like “Dec 15 2–Jan 15 20” (start hour can be 0 through 23 and end hour can be 1 through 24). If multiple periods, use a comma-separated list.

Distribution Assumptions

- Where sample counts are less than 10 (434 / 11,680 rows), the State average distribution has been inserted. ‘Mobile Home’ does not exist in D.C. and is replaced by ‘Single-Family Detached.’

Tenure

Description

The tenancy (owner or renter) of the household occupying the housing unit.

Distribution Data Sources

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Geometry Building Type RECS
- PUMA
- Vacancy Status.

Options

The Tenure options are Owner, Renter, and Not Available. The not applicable option is for vacant units.

Distribution Assumptions

- In ACS, Tenure is reported for occupied units only. By excluding Vacancy Status as a dependency, we assume vacant units share the same Tenure distribution as occupied units. Where sample counts are less than 10 (464 / 11,680 rows), the Census Division by PUMA Metro Status average distribution has been inserted. ‘Mobile Home’ does not exist in D.C. and is replaced by ‘Single-Family Detached.’

Household Has Tribal Persons

Description

The household occupying the housing unit has at least one Tribal person in the household.

Distribution Data Sources

- 2019 5-year PUMS from the University of Minnesota.

Direct Conditional Dependencies

- Federal Poverty Level
- Geometry Building Type RECS
- PUMA.

Options

The Household Has Tribal Persons options are Yes, No, and Not Available. The Not Available option is for Vacant Units.

Distribution Assumptions

- 2,188 / 2,336 PUMA has <10 samples and are falling back to state -level aggregated values. D.C. Mobile Homes do not exist and are replaced with Single-Family Detached.

9 ResStock Outputs

ResStock produces a range of results around energy, housing characteristics, schedules, emissions, and costs. This section overviews the outputs available in the latest ResStock data release. The data dictionary that summarizes these outputs is available with the data release.

9.1 Building Characteristics

The ResStock workflow generates a sample of residential housing units using the conditional distributions and sampling methodology described in Section 7.3. Each housing unit sample is specified using a set of characteristics, which include location, housing type, vintage, heating fuel, building size and geometry, materials, information on the HVAC system, insulation, infiltration, appliances, as well as information on occupant demographics and behavior. These characteristics are used for the model creation process, but they are also available as metadata associated with the results. The metadata is useful for performing analysis and slicing the data into segments. Some characteristics directly impact the OpenStudio model creation (e.g., wall insulation levels), whereas others are meta-parameters used as tags (e.g., ISO/RTO region) or as characteristics that correlate with other energy-relevant characteristics (e.g., vintage). Each of these characteristics is described in detail in Section 8, and are summarized in Table 224. In published ResStock datasets, these housing characteristics are the fields that use the “in” prefix followed by the housing characteristic name, for example “in.windows” for the Windows characteristic. If an upgrade or measure changes a housing characteristic, the post-upgrade characteristic uses the “upgrade” prefix, for example “upgrade.windows.”

Most national ResStock data releases have approximately one sample for every 250 housing units that actually exist in the modeled geography, though this can vary if the sample size is increased or decreased. Taken together, the set of samples describes the housing stock with its intrinsic variety and is used as both an output of ResStock and an input to further steps in the ResStock workflow (see Section 6 for more information about the workflow).

Note that ResStock assigns certain characteristics that are not always used. Two examples of this are *cooling setpoint* in housing units with no cooling system, and *clothes washer usage level* in housing units with no clothes washer. This doesn’t impact the building energy models, this is merely a mechanism that allows for variability in probability distributions if the schedules are used for an upgrade. These characteristics, however, can lead to confusion because they’re preserved in the metadata as being assigned even if they’re not modeled. For further discussion see the the BuildStock Batch Upgrade Scenario documentation.

Table 224. ResStock building characteristic output field names and descriptions

Field Name	**Field Description**
applicability	Whether the upgrade is applicable to this model. Always True for baseline.
bldg_id	The identifier for this model, which can be traced back to the building characteristics input file
completed_status	Whether the simulation for this model was successful or not
in.ahs_region	American Housing Survey region
in.aiannh_area	The sample is or is not located in census-designated American Indian/Alaska Native/Native Hawaiian Area
in.air_leakage_to_outside_ach50	Nominal air infiltration rate
in.applicable	Whether the upgrade is applicable to this model. Always True for baseline.
in.area_median_income	Area median income of the household occupying the housing unit
in.ashrae_iecc_climate_zone_2004	IECC climate zone according to ASHRAE 169 in 2004 and IECC in 2012
in.ashrae_iecc_climate_zone_2004_sub_cz_split	Climate zone according to ASHRAE 169 in 2004 and IECC in 2012, where climate zone 2A is split between counties in TX, LA versus FL, GA, AL, and MS and climate zone 1A is split between FL and HI
in.bathroom_spot_vent_hour	Bathroom spot ventilation daily start hour

Table 224. ResStock building characteristic output field names and descriptions (continued)

Field Name	Field Description
in.battery	The presence, size, location, and efficiency of an on-site battery (not modeled in 2024.2 dataset)
in.bedrooms	Number of bedrooms
in.building_america_climate_zone	Building America climate zone
in.buildstock_csv_path	Where the building characteristics file is located
in.cec_climate_zone	California Energy Code climate zone
in.ceiling_fan	Presence and energy usage of ceiling fans at medium speed
in.census_division	2010 U.S. Census Division
in.census_division_recs	Census Division as used in RECS 2015
in.census_region	2010 U.S. Census Region
in.city	The census-designated city where the sample is located
in.clothes_dryer	The presence, rated efficiency, and fuel type of the clothes dryer in the housing unit
in.clothes_dryer_usage_level	Clothes dryer energy usage level multiplier
in.clothes_washer	Presence and rated efficiency of the clothes washer
in.clothes_washer_presence	Presence of clothes washer
in.clothes_washer_usage_level	Clothes washer energy usage level multiplier
in.cooking_range	Presence and fuel type of the cooking range
in.cooking_range_usage_level	Cooking range energy usage level multiplier
in.cooling_setpoint	Base cooling setpoint with no offset applied
in.cooling_setpoint_has_offset	Presence of cooling setpoint offset
in.cooling_setpoint_offset_magnitude	The magnitude of cooling setpoint offset
in.cooling_setpoint_offset_period	The period during which the cooling setpoint offset is applied
in.cooling_unavailable_days	The number of days in a year the cooling system is unavailable.
in.cooling_unavailable_period	The time during the year when the cooling system is unavailable.
in.corridor	Type of corridor
in.county	County GISJOIN identifier
in.county_and_puma	The GISJOIN identifier for the County and the PUMA that the sample is located
in.county_metro_status	Whether the county is part of a census-defined metro area
in.county_name	The name of the county the building is located in
in.dehumidifier	Presence, water removal rate, and humidity setpoint of dehumidifier (not modeled in 2024.2 dataset)
in.dishwasher	Presence and rated efficiency of dishwasher
in.dishwasher_usage_level	Dishwasher energy usage level multiplier
in.door_area	Area of exterior doors
in.doors	Exterior door material and properties
in.duct_leakage_and_insulation	Duct insulation and leakage to outside from the portion of ducts in unconditioned spaces
in.duct_location	Location of duct system
in.eaves	Depth of roof eaves
in.electric_panel_breaker_space_total_-count	Total breaker spaces on electric panel
in.electric_panel_service_rating..a	Electrical panel service or max current rating (A)
in.electric_panel_service_rating_bin..a	Electrical panel service or max current rating in bins (A)
in.electric_vehicle_battery	The type of battery used by EV
in.electric_vehicle_charge_at_home	Percentage of EV charging that occurs at home
in.electric_vehicle_charger	The type of charger used by EV
in.electric_vehicle_miles_traveled	Annual miles traveled by EV

Table 224. ResStock building characteristic output field names and descriptions (continued)

Field Name	Field Description
in.electric_vehicle_outlet_access	The type of outlet access available for EV
in.electric_vehicle_ownership	Whether the EV is present or not
in.energystar_climate_zone_2023	Climate zones for windows, doors, and skylights per ENERGY STAR guidelines as of 2023
in.federal_poverty_level	Federal poverty level of the household occupying the housing unit
in.generation_and_emissions_assessment_region	Generation and carbon emissions assessment (GEA) region from Cambium 2023
in.geometry_attic_type	Type of attic
in.geometry_building_horizontal_location_mf	Location of the multifamily unit horizontally within the building (left, middle, right)
in.geometry_building_horizontal_location_sfa	Location of the single-family attached unit horizontally within the building (left, middle, right)
in.geometry_building_level_mf	Location of the multifamily unit vertically within the building (bottom, middle, top)
in.geometry_building_number_units_mf	Number of units in the multifamily building in which the housing unit is located
in.geometry_building_number_units_sfa	Number of units in the single-family attached building in which housing unit is located
in.geometry_building_type_acs	American Community Survey building type
in.geometry_building_type_height	RECS 2009 building type with multifamily buildings split out by low-rise, mid-rise, and high-rise
in.geometry_building_type_recs	PUMS 2019 building type
in.geometry_floor_area	Finished floor area bin (American Housing Survey)
in.geometry_floor_area_bin	Finished floor area bin
in.geometry_foundation_type	Type of building foundation
in.geometry_garage	Presence and size of an attached garage
in.geometry_space_combination	Valid combinations of building type, building level MF, attic, foundation, and garage
in.geometry_stories	Number of building stories in which housing unit is located
in.geometry_stories_low_rise	Number of building stories for low rise building in which housing unit is located
in.geometry_story_bin	The building in which housing unit is located has 8 or more versus fewer than 8 stories
in.geometry_wall_exterior_finish	Exterior wall finish material and color
in.geometry_wall_type	Exterior wall material
in.ground_thermal_conductivity	The thermal conductivity of the ground using in foundation and geothermal heat pump heat transfer calculations
in.has_pv	Presence of rooftop PV
in.heating_fuel	Fuel used for primary heating
in.heating_setpoint	Baseline heating setpoint with no offset applied
in.heating_setpoint_has_offset	Presence of heating setpoint offset
in.heating_setpoint_offset_magnitude	The magnitude of heating setpoint offset
in.heating_setpoint_offset_period	The period during which the heating setpoint offset is applied
in.heating_unavailable_days	The number of days in a year the heating system is unavailable.
in.heating_unavailable_period	The time during the year when the heating system is unavailable.
in.holiday_lighting	Presence, energy usage, and schedule of holiday lighting
in.hot_water_distribution	Hot water piping material and insulation level
in.hot_water_fixtures	Hot water fixture usage and flow levels
in.household_has_tribal_persons	The housing unit houses at least one Tribal person

Table 224. ResStock building characteristic output field names and descriptions (continued)

Field Name	Field Description
in.hvac_cooling_autosizing_factor	The additional safety factor applied to the HVAC system cooling capacity
in.hvac_cooling_efficiency	Presence and efficiency of cooling system
in.hvac_cooling_partial_space_conditioning	The fraction of the finished floor area that is cooled by the cooling system
in.hvac_cooling_type	Presence and type of cooling system
in.hvac_has_ducts	Presence of ducts
in.hvac_has_shared_system	Presence of shared HVAC system
in.hvac_has_zonal_electric_heating	Presence of electric baseboard heating
in.hvac_heating_autosizing_factor	The additional safety factor applied to the HVAC system heating capacity
in.hvac_heating_efficiency	Presence and efficiency of primary heating system
in.hvac_heating_type	Presence and type of primary heating system
in.hvac_heating_type_and_fuel	Presence, type, and fuel of primary heating system
in.hvac_secondary_heating_efficiency	Presence and efficiency of secondary heating system
in.hvac_secondary_heating_fuel	Secondary HVAC system heating type and fuel
in.hvac_secondary_heating_heating_type	The type of the secondary heating system
in.hvac_secondary_heating_partial_space_conditioning	Fraction of heat load served by secondary heating system
in.hvac_secondary_heating_type	Secondary HVAC system heating type
in.hvac_shared_efficiencies	Presence and efficiency of shared HVAC system
in.hvac_system_is_faulted	Not used
in.hvac_system_is_scaled	Not used
in.hvac_system_single_speed_ac_airflow	Not used
in.hvac_system_single_speed_ac_charge	Not used
in.hvac_system_single_speed_ashp_airflow	Not used
in.hvac_system_single_speed_ashp_charge	Not used
in.income	Income bin of the household occupying the housing unit
in.income_recs_2015	Income bin of the household occupying the housing unit aligned with the 2015 U.S. EIA RECS
in.income_recs_2020	Income bin of the household occupying the housing unit aligned with the 2020 U.S. EIA RECS
in.infiltration	Air leakage rates for the living and garage spaces
in.insulation_ceiling	Ceiling insulation level (between the living space and unconditioned attic)
in.insulation_floor	Floor insulation level
in.insulation_foundation_wall	Foundation walls insulation level
in.insulation_rim_joist	Insulation level for rim joists
in.insulation_roof	Finished roof insulation level between roof and conditioned space
in.insulation_slab	Slab insulation level
in.insulation_wall	Wall construction type and insulation level
in.interior_shading	Fraction of the window area shaded from the interior in the summer and winter
in.iso_rto_region	ISO or RTO region
in.lighting	Fraction of lighting types
in.lighting_interior_use	Interior lighting usage relative to the national average
in.lighting_other_use	Exterior and garage lighting usage relative to the national average

Table 224. ResStock building characteristic output field names and descriptions (continued)

Field Name	Field Description
in.location_region	Custom ResStock region
in.mechanical_ventilation	Mechanical ventilation type and efficiency
in.metropolitan_and_micropolitan_-statistical_area	The census metropolitan or micropolitan statistical area where this model is located
in.misc_extra_refrigerator	Presence and rated efficiency of extra refrigerator
in.misc_freezer	Presence and rated efficiency of standalone freezer
in.misc_gas_fireplace	Presence of gas fireplace
in.misc_gas_grill	Presence of gas grill
in.misc_gas_lighting	Presence of exterior gas lighting
in.misc_hot_tub_spa	Presence and fuel type of hot tub
in.misc_pool	Presence of pool
in.misc_pool_heater	Presence and fuel type of pool heater
in.misc_pool_pump	Presence and size of pool pump
in.misc_well_pump	Presence and efficiency of well pump
in.natural_ventilation	Schedule of natural ventilation from windows
in.neighbors	Presence and distance between the housing unit and the nearest neighbors to the left and right.
in.occupants	The number of occupants living in the housing unit
in.orientation	Orientation of the building
in.overhangs	Presence, depth, and location of window overhangs
in.plug_load_diversity	Plug load diversity multiplier relative to the national average
in.plug_loads	Plug load usage level relative to the national average
in.puma	The 2010 U.S. Census PUMA where the sample is located
in.puma_metro_status	The PUMA metropolitan status
in.pv_orientation	Presence and orientation of rooftop PV system
in.pv_system_size	Presence and size of rooftop PV system
in.radiant_barrier	Presence of radiant barrier in attic
in.range_spot_vent_hour	Range spot ventilation daily start hour
in.reeds_balancing_area	Regional Energy Deployment System Model balancing area
in.refrigerator	The presence and rated efficiency of the primary refrigerator
in.refrigerator_usage_level	Refrigerator energy usage level multiplier
in.representative_income	The income assumed for the household in this unit for energy burden calculation
in.roof_material	Roof material type
in.solar_hot_water	Presence, size, and location of solar hot water system
in.sqft..ft2	Finished floor area of the representative housing unit
in.state	State
in.state_metro_median_income	The census-supplied median income for households in the metro area where this unit is located.
in.tenure	The tenancy (owner or renter) of the household occupying the housing unit
in.units_represented	Number of housing units the building model represents (this field is no longer used)
in.usage_level	Usage of major appliances relative to the national average
in.upgrade_name	Name of the upgrade applied, or Baseline when no upgrade is applied
in.vacancy_status	Presence of occupants
in.vintage	Range in which the building was constructed
in.vintage_acs	Range in which the building was constructed using ACS bins
in.water_heater_efficiency	Efficiency, type, and heating fuel of water heater

Table 224. ResStock building characteristic output field names and descriptions (continued)

Field Name	Field Description
in.water_heater_fuel	Water heater fuel
in.water_heater_in_unit	Individual water heater present or not present in the housing unit that solely serves the specific housing unit
in.water_heater_location	Water heater location for the housing unit if applicable
in.weather_file_city	City of weather file
in.window_areas	Window to wall ratios of the front, back, left, and right walls
in.windows	Construction type and efficiency levels of windows

In addition to the housing characteristics themselves, several other ResStock outputs receive the "in." prefix. These are inputs that are not provided as housing characteristics, but that are necessary inputs to the model. Most of these values are specified in the project configuration file.

Table 225. ResStock building characteristic output field names and descriptions

Field Name	Field Description
in.emissions_electricity_folders	Relative paths of electricity emissions factor schedule files with hourly values. Paths are relative to the resources folder. If multiple scenarios, use a comma-separated list. File names must contain GEA region names.
in.emissions_electricity_units	Electricity emissions factors units. If multiple scenarios, use a comma-separated list. Only lb/MWh and kg/MWh are allowed.
in.emissions_electricity_values_or_filepaths	Electricity emissions factors values, specified as either an annual factor or an absolute/relative path to a file with hourly factors. If multiple scenarios, use a comma-separated list.
in.emissions_fossil_fuel_units	Fossil fuel emissions factors units. If multiple scenarios, use a comma-separated list. Only lb/MBtu and kg/MBtu are allowed.
in.emissions_fuel_oil_values	Fuel oil emissions factors values, specified as an annual factor. If multiple scenarios, use a comma-separated list.
in.emissions_natural_gas_values	Natural gas emissions factors values, specified as an annual factor. If multiple scenarios, use a comma-separated list.
in.emissions_propane_values	Propane emissions factors values, specified as an annual factor. If multiple scenarios, use a comma-separated list.
in.emissions_scenario_names	Names of emissions scenarios. If multiple scenarios, use a comma-separated list.
in.simulation_control_run_period_begin_day_of_month	The starting day of the starting month for the annual run period.
in.simulation_control_run_period_begin_month	The starting month number (1 = January, 2 = February, etc.) for the annual run period.
in.simulation_control_run_period_calendar_year	The calendar year that determines the start day of week.
in.simulation_control_run_period_end_day_of_month	The ending day of the ending month for the annual run period.
in.simulation_control_run_period_end_month	The end month number (1 = January, 2 = February, etc.) for the annual run period.
in.simulation_control_timestep	Value must be a divisor of 60.
in.utility_bill_detailed_filepaths	n/a
in.utility_bill_electricity_filepaths	n/a
in.utility_bill_electricity_fixed_charges	Electricity utility bill monthly fixed charges. If multiple scenarios, use a comma-separated list.
in.utility_bill_electricity_marginal_rates	Electricity utility bill marginal rates. If multiple scenarios, use a comma-separated list.

Table 225. ResStock building characteristic output field names and descriptions (continued)

Field Name	Field Description
in.utility_bill_fuel_oil_fixed_charges	Fuel oil utility bill monthly fixed charges. If multiple scenarios, use a comma-separated list.
in.utility_bill_fuel_oil_marginal_rates	Fuel oil utility bill marginal rates. If multiple scenarios, use a comma-separated list.
in.utility_bill_natural_gas_fixed_charges	Natural gas utility bill monthly fixed charges. If multiple scenarios, use a comma-separated list.
in.utility_bill_natural_gas_marginal_rates	Natural gas utility bill marginal rates. If multiple scenarios, use a comma-separated list.
in.utility_bill_propane_fixed_charges	Propane utility bill monthly fixed charges. If multiple scenarios, use a comma-separated list.
in.utility_bill_propane_marginal_rates	Propane utility bill marginal rates. If multiple scenarios, use a comma-separated list.
in.utility_bill_scenario_names	Names of utility bill scenarios. If multiple scenarios, use a comma-separated list. If multiple scenarios, use a comma-separated list.
in.utility_bill_simple_filepaths	Relative paths of simple utility rates. Paths are relative to the resources folder. If multiple scenarios, use a comma-separated list.
in.weather_file_latitude	Latitude of location of weather file.
in.weather_file_longitude	Longitude of location of weather file.

9.2 Energy Consumption by Fuel and End Use

The ResStock workflow models each housing unit sample in OpenStudio and EnergyPlus to produce energy consumption of each model at subhourly time steps and then processes the results into ResStock outputs. These outputs are produced by fuel type (e.g., electricity, natural gas) and end use (e.g., lighting, heating). Totals are calculated for each fuel and for all fuels combined. For electricity and all fuels combined, net totals are also calculated, which incorporate the impacts of on-site photovoltaics. The full list of energy consumption outputs from the ResStock workflow is available in Table 226. Note that to date, ResStock has included only consumption of electricity, natural gas, propane, and fuel oil—excluding on-site consumption, wood, coal, or other fuels in its modeling, although the workflow is set up to include these additional fuels. Future releases will likely include wood.

As an output, the energy consumption results are all preceded with an "out." prefix, followed by either the fuel type (e.g., "out.electricity.") or "total." if it is an aggregate of all fuel types, and then the end use, "net." or "total." if it is an aggregate of all end uses in that fuel type.

Table 226. ResStock energy output field names, units, and descriptions

Field Name	Units	Field Description
out.electricity.ceiling_fan.energy_consumption..kwh	kWh	Electricity consumed by ceiling fans
out.electricity.clothes_dryer.energy_consumption..kwh	kWh	Electricity consumed by clothes dryers
out.electricity.clothes_washer.energy_consumption..kwh	kWh	Electricity consumed by clothes washers
out.electricity.cooling.energy_consumption..kwh	kWh	Electricity consumed by cooling systems; excludes usage by fans/pumps
out.electricity.cooling_fans_pumps.energy_consumption..kwh	kWh	Electricity consumed by supply fan (air distribution) or circulating pump (geothermal loop) during cooling
out.electricity.dishwasher.energy_consumption..kwh	kWh	Electricity consumed by dishwashers

Table 226. ResStock energy output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.electricity.ev_charging.energy_consumption..kwh	kWh	Electricity consumed by charging electric vehicles
out.electricity.freezer.energy_consumption..kwh	kWh	Electricity consumed by standalone freezers
out.electricity.heating.energy_consumption..kwh	kWh	Electricity consumed by heating systems; excludes usage by fans/pumps
out.electricity.heating_fans_pumps.energy_consumption..kwh	kWh	Electricity consumed by supply fan (air distribution) or circulating pump (hydronic distribution or geothermal loop) during heating
out.electricity.heating_hp_bkup.energy_consumption..kwh	kWh	Electricity consumed by heat pump backup; excludes usage by heat pump backup fans/pumps
out.electricity.heating_hp_bkup_fa.energy_consumption..kwh	kWh	Electricity consumed by supply fan (air distribution) or circulating pump (hydronic distribution) during heat pump backup
out.electricity.hot_water.energy_consumption..kwh	kWh	Electricity consumed by hot water system excludes recirculation pump and solar thermal pump
out.electricity.hot_water_solar_th.energy_consumption..kwh	kWh	Electricity consumed by the solar hot water system pump
out.electricity.lighting_exterior.energy_consumption..kwh	kWh	Electricity consumed by exterior lighting
out.electricity.lighting_garage.energy_consumption..kwh	kWh	Electricity consumed by lighting in the garage
out.electricity.lighting_interior.energy_consumption..kwh	kWh	Electricity consumed by interior lighting
out.electricity.mech_vent.energy_consumption..kwh	kWh	Electricity consumed by mechanical ventilation system
out.electricity.net.energy_consumption..kwh	kWh	Total electricity consumed subtracts any power produced by PV or generators
out.electricity.permanent_spa_heat.energy_consumption..kwh	kWh	Electricity consumed by spa heating
out.electricity.permanent_spa_pump.energy_consumption..kwh	kWh	Electricity consumed by spa pump
out.electricity.plug_loads.energy_consumption..kwh	kWh	Electricity consumed by plug loads not elsewhere accounted for
out.electricity.pool_heater.energy_consumption..kwh	kWh	Electricity consumed by pool heaters
out.electricity.pool_pump.energy_consumption..kwh	kWh	Electricity consumed by pool pumps
out.electricity.pv.energy_consumption..kwh	kWh	Energy produced by rooftop PV systems. Negative value for any power produced.
out.electricity.range_oven.energy_consumption..kwh	kWh	Electricity consumed by range and oven
out.electricity.refrigerator.energy_consumption..kwh	kWh	Electricity consumed by refrigerators
out.electricity.television.energy_consumption..kwh	kWh	Electricity consumed by televisions
out.electricity.total.energy_consumption..kwh	kWh	Total electricity consumed
out.electricity.well_pump.energy_consumption..kwh	kWh	Electricity consumed by the well pump, if present

Table 226. ResStock energy output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.fuel_oil.heating.energy_consumption..kwh	kWh	Propane consumed by propane heating systems
out.fuel_oil.hot_water.energy_consumption..kwh	kWh	Propane consumed by propane hot water systems
out.fuel_oil.total.energy_consumption..kwh	kWh	Total propane energy consumed
out.hot_water.clothes_washer..gal	gal	Hot water consumed by the clothes washer
out.hot_water.dishwasher..gal	gal	Hot water consumed by the dishwasher
out.hot_water.distribution_waste..gal	gal	TODO
out.hot_water.fixtures..gal	gal	Hot water consumed by sinks and showers
out.natural_gas.clothes_dryer.energy_consumption..kwh	kWh	Natural gas consumed by natural gas clothes dryers
out.natural_gas.fireplace.energy_consumption..kwh	kWh	Natural gas consumed by natural gas fireplaces
out.natural_gas.grill.energy_consumption..kwh	kWh	Natural gas consumed by natural gas grills
out.natural_gas.heating.energy_consumption..kwh	kWh	Natural gas consumed by natural gas heating systems
out.natural_gas.heating_hp_bkup.energy_consumption..kwh	kWh	Natural gas consumed by heat pump backup
out.natural_gas.hot_water.energy_consumption..kwh	kWh	Natural gas consumed by natural gas hot water systems
out.natural_gas.lighting.energy_consumption..kwh	kWh	Natural gas consumed by natural gas lighting
out.natural_gas.permanent_spa_heat.energy_consumption..kwh	kWh	Natural gas consumed by spa heating
out.natural_gas.permanent_spa_pump.energy_consumption..kwh	kWh	Natural gas consumed by spa pump
out.natural_gas.pool_heater.energy_consumption..kwh	kWh	Natural gas consumed by natural gas pool heaters
out.natural_gas.range_oven.energy_consumption..kwh	kWh	Natural gas consumed by natural gas range and oven
out.natural_gas.total.energy_consumption..kwh	kWh	Total natural gas consumed
out.propane.clothes_dryer.energy_consumption..kwh	kWh	Propane consumed by propane clothes dryers
out.propane.heating.energy_consumption..kwh	kWh	Propane consumed by propane heating systems
out.propane.heating_hp_bkup.energy_consumption..kwh	kWh	Propane consumed by heat pump backup
out.propane.hot_water.energy_consumption..kwh	kWh	Propane consumed by propane hot water systems
out.propane.range_oven.energy_consumption..kwh	kWh	Propane consumed by propane range and oven
out.propane.total.energy_consumption..kwh	kWh	Total propane energy consumed
out.site_energy.net.energy_consumption..kwh	kWh	Total site energy consumed subtracts any power produced by PV or generators
out.site_energy.total.energy_consumption..kwh	kWh	Total site energy consumed

For each of the outputs above, there are five related columns:

- out.<fuel>.<enduse>.energy_savings..kwh: The difference in energy consumption between the baseline and this upgrade.
- out.<fuel>.<enduse>.energy_consumption_intensity..kwh: The energy consumption per floor area of the home.
- out.<fuel>.<enduse>.energy_savings_intensity..kwh: The difference in energy consumption between the baseline and this upgrade per floor area of the home.
- calc.weighted.<fuel>.<enduse>.energy_consumption..tbtu: The energy consumption scaled by the weight to represent the national total for this value.
- calc.weighted.<fuel>.<enduse>.energy_savings..tbtu: The difference in energy consumption between the baseline and this upgrade, scaled by the weight to represent the national total for this value.

9.3 Cost Multipliers

The ResStock workflow calculates and outputs certain values to support the calculation of costs of implementation of upgrades and upgrade packages. These are values that are available to scale measure implementation cost—for example, the total square feet of exterior window area in a housing unit model sample that can be multiplied by a user-provided window cost per square foot for a specific measure to get a per-housing-unit measure cost. They are calculated from the building energy models. ResStock currently provides the values listed in Table 227. In published ResStock datasets, these cost multipliers are the fields that use the "out.params" prefix, for example "out.params.window_area..ft2." The exception is that "out.params.floor_area_conditioned..ft2" has to-date been published as "in.sqft..ft2"

Table 227. ResStock cost multiplier output field names, units, and descriptions

Field Name	Units	Description
out.params.door_area..ft2	ft^2	Door Area
out.params.duct_unconditioned_surface_area..ft2	ft^2	Duct Unconditioned Surface Area
out.params.floor_area_attic..ft2	ft^2	Floor Area, Attic
out.params.floor_area_attic_insulation_increase..ft2_delta_r_value	$ft^2 * \Delta$ R-value	Floor Area, Attic * Insulation Increase
out.params.floor_area_conditioned..ft2	ft^2	Floor Area, Conditioned
out.params.floor_area_conditioned_infiltration_reduction..ft2_delta_ach50	$ft^2 * \Delta$ ACH50	Floor Area, Conditioned * Infiltration Reduction
out.params.floor_area_foundation..ft2	ft^2	Floor Area, Foundation
out.params.floor_area_lighting..ft2	ft^2	Floor Area, Lighting
out.params.flow_rate_mechanical_ventilation..cfm	cfm	Flow Rate, Mechanical Ventilation
out.params.hvac_geothermal_loop_borehole_trench_count	count	The number or boreholes used in the geothermal system
out.params.hvac_geothermal_loop_borehole_trench_length..ft	ft	The length/depth of each borehole used in the geothermal system
out.params.rim_joist_area_above_grade_exterior..ft2	ft^2	Rim Joist Area, Above-Grade, Exterior
out.params.roof_area..ft2	ft^2	Roof Area
out.params.size_cooling_system_primary..kbtu_per_hr	kBtu/h	Size, Cooling System Primary
out.params.size_heat_pump_backup_primary..kbtu_per_hr	kBtu/h	Size, Heat Pump Backup Primary
out.params.size_heating_system_primary..kbtu_per_hr	kBtu/h	Size, Heating System Primary

Table 227. ResStock cost multiplier output field names, units, and descriptions

Field Name	Units	Description
out.params.size_heating_system_secondary..kbtu_per_hr	kBtu/h	Size, Heating System Secondary
out.params.size_water_heater..gal	gal	Size, Water Heater
out.params.slab_perimeter_exposed_conditioned..ft	ft	Slab Perimeter, Exposed, Conditioned
out.params.wall_area_above_grade_conditioned..ft2	ft^2	Wall Area, Above-Grade, Conditioned
out.params.wall_area_above_grade_exterior..ft2	ft^2	Wall Area, Above-Grade, Exterior
out.params.wall_area_below_grade..ft2	ft^2	Wall Area, Below-Grade
out.params.window_area..ft2	ft^2	Window Area

9.4 Emissions

The ResStock workflow includes the capability of including emissions factors as supplemental inputs, which are then used to calculate the corresponding emissions outputs. These outputs are generated by end use and fuel type, as well as per-fuel totals. Total emissions impacts of a measure across fuels are calculated from ResStock results.

9.4.1 Emissions From On-Site Combustion (Scope 1)

The ResStock workflow currently accepts emissions factors for non-electric energy consumption as annual values only. Our typical approach is to use the values from Table 7.1.2(1) of PDS-01 of BSR/RESNET/ICCC 301 Addendum B, CO_2 Index (Network 2022), which account for both combustion and pre-combustion (e.g., methane leakage) impacts. These are 147.3 lb/MMBtu (228.5 kg/MWh) for natural gas, 177.8 lb/MMBtu (275.8 kg/MWh) for propane, and 195.9 lb/MMBtu (303.9 kg/MWh) for fuel oil. ResStock then outputs the associated carbon-equivalent emissions for every fuel and end-use combination.

If multiple emissions scenarios are being run, ResStock will output values for each fuel for each end use for each scenario, even if that particular fuel's emissions factors do not differ between scenarios. This occurs frequently when we run multiple electricity emissions scenarios with different values for emissions factors related to electricity generation that all use the same emissions factors for on-site non-electric fuel consumption. The full list of emissions output fields from non-electric energy consumption is in Table 228. In published ResStock datasets, we convert the units on these results to kilograms of CO_2 equivalent emissions. These are the fields in public datasets that begin "out.emissions.natural_gas," "out.emissions.propane," and "out.emissions.fuel_oil."

9.4.2 Emissions From Electricity Generation (Scope 2)

The ResStock workflow currently accepts emissions factors for electricity consumption as either annual or hourly values. We have used several approaches in selecting electricity emissions factors for use. Our most commonly used approach is to include multiple scenarios, generally relying on data from NREL's Cambium database (Gagnon et al. 2025). When using Cambium data, we use multiple standard scenarios (potential futures of the electric grid) as a type of sensitivity. ResStock releases generally have five long-run marginal emissions scenarios with a computed a levelized factor over a 15 or 25 year lifetime with a 3% discount rate, starting a few years in the future. We then use timeseries (hourly) data at the GEA geographic resolution. ResStock also published average emissions rates, which are a simple average from the beginning to the end of the analysis period.

The full list of emissions output fields from electric energy consumption is in Table 228. In published ResStock datasets, we convert the units on these results to kilograms of CO_2 equivalent emissions. These are the fields in public datasets that begin "out.emissions.electricity."

Table 228. ResStock emissions output field names, units, and descriptions

Field Name	Units	Field Description

Table 228. ResStock emissions output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.emissions.electricity.lrmer_-mid_case_25..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 mid case scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.electricity.lrmer_-mid_case_15..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 mid case scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.electricity.lrmer_-high_re_cost_25..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 high renewable cost scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.electricity.lrmer_-high_re_cost_15..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 high renewable cost scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.electricity.lrmer_-low_re_cost_25..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 low renewable cost scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.electricity.lrmer_-low_re_cost_15..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 low renewable cost scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.electricity.lrmer_-low_re_cost_high_ng_price_-25..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 low renewable cost high natural gas price scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.electricity.lrmer_-low_re_cost_high_ng_price_-15..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 low renewable cost high natural gas price scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.electricity.lrmer_-high_re_cost_low_ng_price_-25..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 high renewable cost low natural gas price scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.electricity.lrmer_-high_re_cost_low_ng_price_-15..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 high renewable cost low natural gas price scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.electricity.aer_-high_re_cost_avg..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 high renewable cost scenario with average emissions rates averaged from 2025-2050.
out.emissions.electricity.aer_-high_re_cost_low_ng_price_-avg..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 high renewable cost low natural gas price scenario with average emissions rates averaged from 2025-2050.
out.emissions.electricity.aer_low_-re_cost_avg..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 low renewable cost scenario with average emissions rates averaged from 2025-2050.

Table 228. ResStock emissions output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.emissions.electricity.aer_low_re_cost_high_ng_price_avg..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 low renewable cost high natural gas price scenario with average emissions rates averaged from 2025-2050.
out.emissions.electricity.aer_mid_case_avg..co2e_kg	co2e_kg	Scope 2 emissions from onsite use of electricity using Cambium 2024 mid case scenario with average emissions rates averaged from 2025-2050.
out.emissions.fuel_oil.total..co2e_kg	co2e_kg	Scope 1 emissions from onsite combustion of fuel oil
out.emissions.natural_gas.total..co2e_kg	co2e_kg	Scope 1 emissions from onsite combustion of natural gas
out.emissions.propane.total..co2e_kg	co2e_kg	Scope 1 emissions from onsite combustion of propane
out.emissions.total.lrmer_mid_case_25..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 mid case scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.total.lrmer_mid_case_15..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 mid case scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.total.lrmer_high_re_cost_25..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 high renewable cost scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.total.lrmer_high_re_cost_15..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 high renewable cost scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.total.lrmer_low_re_cost_25..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 low renewable cost scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.total.lrmer_low_re_cost_15..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 low renewable cost scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.total.lrmer_low_re_cost_high_ng_price_25..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 low renewable cost high natural gas price scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.total.lrmer_low_re_cost_high_ng_price_15..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 low renewable cost high natural gas price scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027

Table 228. ResStock emissions output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.emissions.total.lrmer_high_re_cost_low_ng_price_25..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 high renewable cost low natural gas price scenario with long run marginal emissions rate levelized by 3% over 25 years
out.emissions.total.lrmer_high_re_cost_low_ng_price_15..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 high renewable cost low natural gas price scenario with long run marginal emissions rate levelized by 3% over 15 years starting in 2027
out.emissions.total.aer_high_re_cost_avg..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 high renewable cost scenario with average emissions rates averaged from 2025-2050.
out.emissions.total.aer_high_re_cost_low_ng_price_avg..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 high renewable cost low natural gas price scenario with average emissions rates averaged from 2025-2050.
out.emissions.total.aer_low_re_cost_avg..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 low renewable cost scenario with average emissions rates averaged from 2025-2050.
out.emissions.total.aer_low_re_cost_high_ng_price_avg..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 low renewable cost high natural gas price scenario with average emissions rates averaged from 2025-2050.
out.emissions.total.aer_mid_case_avg..co2e_kg	co2e_kg	Emissions using on-site fossil fuel rates from ANSI/RESNET and electricity using Cambium 2024 mid case scenario with average emissions rates averaged from 2025-2050.

For each of the outputs above, there are three related columns:

- `out.emissions_reduction.<fuel>.<scenario>.co2e_kg`: The difference in emissions between the baseline and this upgrade.
- `calc.weighted.emissions.<fuel>.<scenario>.co2e_mmt`: The emissions scaled by the weight to represent the national total for this value.
- `calc.weighted.emissions_reduction.<fuel>.<scenario>.co2e_mmt`: The difference in emissions between the baseline and this upgrade, scaled by the weight to represent the national total for this value.

9.5 Utility Bills

Utility bills are calculated using state-average utility rates plus a fixed charge in this ResStock dataset. This dataset includes the addition of energy prices for Alaska and Hawaii. A summary is below.

Utility costs are calculated for electricity, natural gas, propane, and No. 2 fuel oil. Wood, coal, or district steam are not modeled and there is no method in this dataset to calculate those bills as part of the data release. When possible, project or location specific energy rates and fixed charges should be used to calculate utility bills instead of the pre-calculated bills provided in this documentation that are based on state-averaged rates.

Table 229. ResStock utility bill output field names, units, and descriptions

Field Name	Units	Description
out.utility_bills.total_bill..usd	$	Annual total charges for electricity, fuel oil, natural gas, and propane
out.utility_bills.electricity_bill..usd	$	Annual total charges for electricity
out.utility_bills.fuel_oil_bill..usd	$	Annual total charges for fuel oil
out.utility_bills.natural_gas_bill..usd	$	Annual total charges for natural gas
out.utility_bills.propane_bill..usd	$	Annual total charges for propane
out.utility_bills.total_bill_savings..usd	$	Annual total savings for electricity, fuel oil, natural gas, and propane
out.utility_bills.electricity_bill_savings..usd	$	Annual total savings for electricity
out.utility_bills.fuel_oil_bill_savings..usd	$	Annual total savings for fuel oil
out.utility_bills.natural_gas_bill_savings..usd	$	Annual total savings for natural gas
out.utility_bills.propane_bill_savings..usd	$	Annual total savings for propane

ResStock results can also be used as inputs to calculate utility bills using other rate structures, such as time-of-use electricity rates or tiered rates. However, these calculations are currently not included in the primary ResStock workflow or any published datasets.

9.5.1 Residential Electricity Bills

ResStock models state-average variable electricity rates. The static charges were calculated using data from the OpenEI Utility Rate Database (URDB) from data in May 2025[11].

The ResStock workflow is able to accept a limited range of utility rate inputs and output the corresponding utility bills. The inputs available are fixed charges and volumetric rates for each modeled fuel (typically electricity, natural gas, propane, and fuel oil). These can vary by any one housing characteristic, such as State. Multiple scenarios may be specified. For the list of utility bill outputs, see Table 229. Data from all utilities listed in URDB was averaged together to get a nationwide value of $13.80/month or $165.60/year. Utility rates containing the following portions of words, or full words, were removed from the analysis: agri, irrig, farm, pump, snow, vehicle, oil, cotton gin, outdoor light, security light, street, wholesale, water heater, recr, heating, x-ray, closed rate, electric motor standby, season, relig, resort, govern, grain, cabin, swim, commercial, exper, and cottage. Rates that had static charges less than $0 and more than $50 were removed. Rates before the year 2015 were also removed. Incomplete rates, rates that did not have a monthly fixed charge, rates specific to transmission voltage, rates specific to a time of use rate, or non-residential rates were removed too.

Customer count, sales, and revenues for each state were taken from Form EIA-861 year 2023 for the total electric industry(U.S. Energy Information Administration 2024a). The data was downloaded in May 2025. To find the variable electricity rate, the following equation was used for each state:

$$\text{Variable electricity rate} = \frac{\text{Total revenue} - (\text{Fixed cost} \times \text{Number of customers})}{\text{Total sales}} \tag{9.1}$$

This resulted in state average variable electricity rates that ranged from $0.0957 kWh in Washington to $0.3965 kWh in Hawaii.

The full year electricity bill was then calculated for each modeled dwelling unit using the dwelling unit's electricity consumption, the state average variable electricity rate, and the nationwide static charge.

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[11] https://apps.openei.org/USURDB/

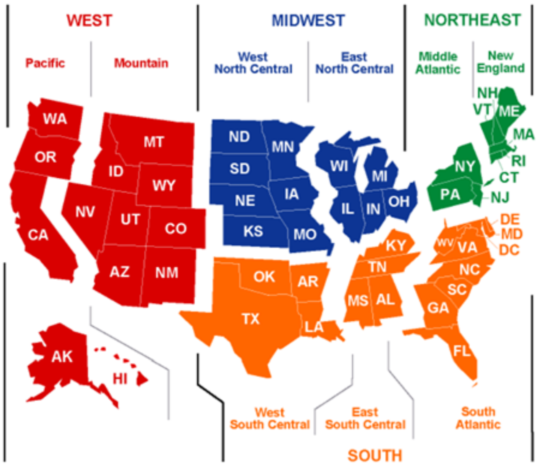

Figure 15. Census regions for natural gas fixed charges

$$\text{Annual electricity bill} = (\text{Fixed cost per month} \times 12 \text{ months}) + (\text{Electricity consumption} \times \text{Variable electricity rate}) \tag{9.2}$$

9.5.2 Residential Natural Gas Bills

Natural gas bills are only calculated for dwelling units that have natural gas consumption. For natural gas bills, we used the census-dependent customer charges from a 2015 American Gas Association report(American Gas Association 2015). The customer charges are reproduced below, along with the census regions assumed for the report.

Table 230. Natural gas census regions and fixed charges

Census Region	Rate $
New England	13.50
Middle Atlantic	14.60
East North Central	11.38
West North Central	13.16
South Atlantic	10.00
East South Central	14.00
West South Central	13.24
Mountain	10.80
Pacific	4.95

2023 EIA data was used for the price, consumption, and number of consumers.

Natural gas prices from the EIA 2023 "Residential Price" Data Series were used for the "Annual" period(U.S. Energy Information Administration 2025b). Some 2024 prices were available, but 2023 prices were used to ensure consistency across the data. This data was released in May 2025.

The natural gas consumption values came from the EIA 2023 "Volumes Delivered to Residential" data series for the "Annual" period(U.S. Energy Information Administration 2025a). Like natural gas prices, some 2024 values were available, but 2023 consumption values were used and this data was also released in May 2025.

The number of consumers per state used in this ResStock dataset were released in April 2025(U.S. Energy Information Administration 2025c). The data series used was the "No. of Residential Consumers". None of the states had 2024 data available at the time of writing, therefore all states and Washington D.C. used 2023 data.

The volumetric rate for each state and Washington D.C. is seen in the following equation.

$$\text{Volumetric natural gas rate} = \frac{(\text{Consumption} \times \text{price}) - (\text{Fixed cost per month} \times 12 \text{ months} \times \text{Number of consumers})}{(\text{Consumption} \times \text{Price})} \tag{9.3}$$

The rates ranged from \$0.76therm in North Dakota to \$4.63therm in Hawaii.

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

$$\text{Annual natural gas bill} = (\text{Fixed cost per month} \times 12 \text{ months}) + (\text{Natural gas consumption} \times \text{Volumetric natural gas rate}) \tag{9.4}$$

If the dwelling unit had no natural gas consumption in the baseline, but then received a gas furnace, then the dwelling unit had natural gas charges only in the upgrade scenario. In all other cases, a dwelling unit that originally had no natural gas consumption will not have any natural gas consumption in any other upgrade scenarios. If the dwelling unit had natural gas in the baseline, but then a measure upgrade caused there to be no gas, there is no natural gas bill for that measure upgrade. Fixed charges are applied monthly if there is a gas connection or gas consuming appliance, even if the month had zero natural gas consumption.

9.5.3 Residential Propane Bills

Propane costs for all states except for Alaska were taken from the 5/21/2025 release of the Weekly Heating Oil and Propane Prices from the EIA(U.S. Energy Information Administration 2025d).The data series was "Residential Propane" and the period was "Weekly". Weekly prices from December 2024 through February 2025 were averaged together. State prices were used first if available. If state values were not available, Petroleum Administration for Defense District (PADD) values were used. If PADD values were not available, the U.S. weekly prices were used. PADD regions are reproduced below for clarity(U.S. Energy Information Administration).

Table 231. PADD regions

PADD Region	States
PADD 1A (New England)	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
PADD 1B (Central Atlantic)	Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania
PADD 1C (Lower Atlantic)	Florida, Georgia, North Carolina, South Carolina, Virginia, West Virginia
PADD 2 (Midwest)	Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, Wisconsin
PADD 3 (Gulf Coast)	Alabama, Arkansas, Louisiana, Mississippi, New Mexico, Texas
PADD 4 (Rocky Mountain)	Colorado, Idaho, Montana, Utah, Wyoming
PADD 5 (West Coast)	Alaska, Arizona, California, Hawaii, Nevada, Oregon, Washington

States using averaged U.S. weekly prices are Arizona, California, Oregon, Washington, Hawaii, and Nevada. States using their PADD region prices include Louisiana, New Mexico, West Virginia, South Carolina, Wyoming, and the District of Columbia. All other states, aside from Alaska, used their own state prices from EIA. Prices ranged from \$1.64/gallon in Iowa to \$4.75/gallon in Florida.

Propane prices for Alaska were taken from the Alaska Housing Finance Corporation's Fuel Survey dated 2025-03-01(Alaska Housing Finance Corporation 2025).This data is typically used in the AkWarm energy modeling software. Taxes were included in the prices. The Alaska state average price using this survey is \$8.11/gallon.

Propane bills often have fixed or static charges. However, due to lack of national information on these values, these fixed or static charges were assumed to be zero.

9.5.4 Residential No. 2 Fuel Oil Bills

No. 2 fuel oil prices for all states, except Alaska, were taken from the 5/21/2025 release of the Weekly Heating Oil and Propane Prices from the EIA(U.S. Energy Information Administration 2025e). The data series was "Residential Heating Oil" and the period was "Weekly". Weekly prices from December 2024 through February 2025 were averaged together. State prices were used first, and if those were not available, PADD regions were used next and then U.S. prices. PADD regions are the same for No. 2 fuel oil and propane.

States using averaged U.S. weekly prices include Arizona, Arkansas, California, Colorado, Hawaii, Idaho, Louisiana, Mississippi, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming. States using their PADD prices include District of Columbia, Illinois, Florida, Georgia, Kansas, Missouri, North Dakota, Oklahoma, South Carolina, South Dakota, Tennessee, and West Virginia. All other states, aside from Alaska, used their own state prices. Prices ranged from $2.75/gallon in Nebraska to $4.02/gallon in Delaware.

Alaska prices come from the Alaska Fuel Price Report: Winter 2025(Divsion of Community and Regional Affairs 2025). The average unsubsidized No. 2 heating fuel price of 93 communities was $6.48/gallon, and this will be used for the whole state of Alaska. Notable exclusions from the Alaska Fuel Price Report data include Anchorage and Mat-Su. Please read the Alaska Fuel Price report for other relevant assumptions.

Heating fuel bills often have fixed or static charges. However, due to lack of national information on these values, these fixed or static charges were assumed to be zero.

9.6 Energy Burden

Energy burden is calculated as the ratio of two values from ResStock data. The first is the energy bill, which is calculated for each individual housing unit model in an analysis as described in the above section. The second is the representative household income, which is converted from income bin and other household characteristics described in Section 8.11.2. The energy burden is the energy bill total divided by the representative household income, typically expressed as a percentage. As the utility bill does not account for financial assistance such as LIHEAP, energy burden may be overestimated for low-income households who may qualify for those assistance. Additionally, the representative income is in 2019 USD, reflecting the vintage of PUMS used to derived the data. The dollar value of the utility bill is typically more recent and thus may not align with that of the income denominator.

When this field is available in public datasets, it begins with "out.energy_burden."

9.7 Schedules

ResStock optionally outputs schedules into the timeseries files. These schedules include energy use schedules as fractions (0-1) and unavailable period schedules from HVAC, power outage, and vacancy periods.

Table 232. ResStock schedule output field names, units, and descriptions

Field Name	Units	Field Description
out.schedules_ceiling_fan	frac	Ceiling fan energy use schedule.
out.schedules_clothes_dryer	frac	Clothes dryer energy use schedule.
out.schedules_clothes_washer	frac	Clothes washer energy use schedule.
out.schedules_cooking_range	frac	Cooking range and oven energy use schedule.
out.schedules_dishwasher	frac	Dishwasher energy use schedule.
out.schedules_hot_water_clothes_washer	frac	Clothes washer hot water use schedule.
out.schedules_hot_water_dishwasher	frac	Dishwasher hot water use schedule.
out.schedules_hot_water_fixtures	frac	Fixtures (sinks, showers, baths) hot water use schedule.
out.schedules_lighting_garage	frac	Garage lighting energy use schedule.
out.schedules_lighting_interior	frac	Interior lighting energy use schedule.
out.schedules_no_space_cooling	0,1	Cooling unavailable period.
out.schedules_no_space_heating	0,1	Heating unavailable period.

Table 232. ResStock schedule output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.schedules_occupants	frac	Occupant heat gain schedule.
out.schedules_plug_loads_other	frac	Other plug load energy use schedule.
out.schedules_plug_loads_tv	frac	Television plug load energy use schedule.
out.schedules_power_outage	0,1	Power outage unavailable period.
out.schedules_vacancy	0,1	Vacancy unavailable period.

9.8 Electrical Panels

For electrical panel, occupied capacity and breaker spaces are tabulated by end use. The total occupied capacity and spaces are calculated as well as their headroom, or the amount of capacity or space left unused. In public ResStock datasets, these fields are prefixed with "out.electric_panel" and described in 233. For capacity, the total occupied load (W) can be calculated using different methods and will be labeled accordingly. In the public datasets, results are available for the 2023 load-based (NEC 220.83) method only for existing dwellings. See Section 8.10 for the method description. The occupied capacity (A) is converted from occupied load (W) by dividing by 240V, the panel voltage, and then subtracted from the input field "in.electrical_panel_service_rating"" (A) to get the headroom capacity (A). The headroom capacity is used to determine capacity constraint – the panel is considered capacity-constrained if headroom is negative and unconstrained otherwise. This outcome is useful to account for any additional costs needed to resolve the constraint, such as through an electrical panel or service upgrade, or by using lower power appliances as an alternative. Users are encouraged to calculate the capacity constraint on their own to reflect their desired margin of error.

For breaker space, total rated count is labeled as an input metric in table 224. This is actually derived from the breaker space headroom, which is probabilistically assigned based on the panel ampacity rating and other housing characteristics, and a tabulation of electrical equipment in the baseline home. In the upgrade simulations, the total breaker space count is carried over from the baseline simulation and the headroom count is recalculated according to the content of the upgrade package. See Section 8.10 for details. For ease of interpretation by mirroring the structure of the capacity metrics, total breaker space count is labeled as an input just like the panel service rating. All occupied and headroom tabulations are labeled as outputs. Breaker space headroom is used to calculate the space constraint, which exists when the headroom count is negative. The overall panel constraint is summarized into "no constraint", "space constrained only", "capacity constrained only", or "capacity and space constrained".

All results should be interpreted with uncertainty in mind, even if they look reasonable. The prediction of the panel service rating and headroom space do not account for all electrical and connected loads in the model. As a result, the capacity headroom can be negative for a model in the baseline, although it is uncommon. This can be interpreted as the house already being constrained prior to any upgrade and is consistent with anecdotal observations that some houses do trip their breakers often, an indication of a capacity shortfall. On the otherhand, the breaker space headroom in the baseline can never be negative because our modeling approach prevents this by sampling a non-negative headroom count directly. This is also consistent with the physical constraint of breaker space.

Table 233. ResStock electrical panel output field names, units, and descriptions

Field Name	Units	Field Description
out.params.panel_load_total_load.2023_nec_existing_dwelling_load_based..w	W	Total service feeder load calculated per selected NEC method
out.params.panel_load_occupied_capacity.2023_nec_existing_dwelling_load_based..a	A	Total capacity occupied on the panel, calculated as total load (W) divided by panel voltage (240V)
out.params.panel_load_headroom_capacity.2023_nec_existing_dwelling_load_based..a	A	Available capacity on the panel, calculated as panel service rating (A) minus total occupied capacity (A)
out.params.panel_load_heating..w	W	Sum of space heating system and heat pump heating electric loads. For the load calculation, only the max of heating or cooling is used, not both

Table 233. ResStock electrical panel output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.params.panel_load_cooling..w	W	Sum of space cooling system and heat pump cooling electric loads. For the load calculation, only the max of heating or cooling is used, not both
out.params.panel_load_hot_water..w	W	Sum of water heating system electric loads, for electric only
out.params.panel_load_clothes_dryer..w	W	Sum of clothes dryer electric loads, for electric only
out.params.panel_load_dishwasher..w	W	Sum of dishwasher electric loads
out.params.panel_load_range_oven..w	W	Sum of range/oven electric loads, for electric only
out.params.panel_load_mech_vent..w	W	Sum of mechanical ventilation electric loads
out.params.panel_load_permanent_spa_heat..w	W	Sum of permanent spa heater electric load, for electric only
out.params.panel_load_permanent_spa_pump..w	W	Sum of permanent spa pump electric loads
out.params.panel_load_pool_heater..w	W	Sum of pool heater electric loads
out.params.panel_load_pool_pump..w	W	Sum of pool pump electric loads
out.params.panel_load_well_pump..w	W	Sum of well pump electric loads
out.params.panel_load_ev_charging..w	W	Sum of electric vehicle charging equipment electric loads
out.params.panel_load_other..w	W	Sum of other electric loads, including but not limited to lighting/general receptacles at 3 W/sqft, refrigerator, microwave, and garbage disposal
out.params.panel_breaker_space_occupied_savings_count	count	TODO
out.params.panel_breaker_space_occupied_count	count	Total number of occupied spaces on the panel
out.params.panel_breaker_space_headroom_count	count	Available spaces, calculated as total rated spaces minus occupied spaces
out.params.panel_breaker_space_heating_count	count	Sum of heating system and heat pump heating occupied spaces
out.params.panel_breaker_space_cooling_count	count	Sum of cooling system and heat pump cooling occupied spaces
out.params.panel_breaker_space_hot_water_count	count	Sum of water heating system occupied spaces
out.params.panel_breaker_space_clothes_dryer_count	count	Sum of clothes dryer occupied spaces
out.params.panel_breaker_space_dishwasher_count	count	Sum of dishwasher occupied spaces
out.params.panel_breaker_space_range_oven_count	count	Sum of range/oven occupied spaces
out.params.panel_breaker_space_mech_vent_count	count	Sum of mechanical ventilation occupied spaces
out.params.panel_breaker_space_permanent_spa_heat_count	count	Sum of permanent spa heater occupied spaces
out.params.panel_breaker_space_permanent_spa_pump_count	count	Sum of permanent spa pump occupied spaces
out.params.panel_breaker_space_pool_heater_count	count	Sum of pool heater occupied spaces
out.params.panel_breaker_space_pool_pump_count	count	Sum of pool pump occupied spaces
out.params.panel_breaker_space_well_pump_count	count	Sum of well pump occupied spaces

Table 233. ResStock electrical panel output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.params.panel_breaker_space_ev_charging_count	count	Sum of electric vehicle charging occupied spaces
out.params.panel_breaker_space_other_count	count	Sum of other electric load occupied spaces
out.params.panel_constraint_capacity.2023_nec_existing_dwelling_load_based	bool	Whether electric panel is capacity-constrained per the given method, defined as when out.params.panel_load_headroom_capacity.2023_nec_existing_dwelling_load_based.a < 0
out.params.panel_constraint_breaker_space	bool	Whether electric panel is space-constrained, defined as when out.panel.breaker_space.headroom_count < 0
out.params.panel_constraint_overall.2023_nec_existing_dwelling_load_based	categorical	Summarize overall electric panel constraint per the given method as "no constraint", "space constrained only", "capacity constrained only", or "capacity and space constrained"
out.params.panel_load_total_load.2023_nec_existing_dwelling_load_based..w.savings	W	For an upgrade measure only, total service feeder load reduced per selected NEC method
out.params.panel_load_occupied_capacity.2023_nec_existing_dwelling_load_based.a.savings	A	For an upgrade measure only, total occupied capacity reduced per selected NEC method
out.panel.breaker_space.occupied_count.savings	count	For an upgrade measure only, total number of occupied spaces reduced

9.9 Other Outputs

The ResStock workflow can optionally output any variable available in EnergyPlus. We regularly use this capability for a variety of purposes, including modeling improvement and validation, debugging, special purpose variables for specific projects, and additional variables to publish as part of public datasets.

Table 234 shows a list of output variables that are not covered in other headings in this section but that we have typically included in many of our recent public datasets, where they begin with “out.x.”

Table 234. Other ResStock results output field names, units, and descriptions

Field Name	Units	Field Description
out.cooling_unavailable_period		Cooling unavailable period.
out.electricity.summer.peak.kw	kW	Maximum power value in Jun/Jul/Aug
out.electricity.winter.peak.kw	kW	Maximum power value in Dec/Jan/Feb
out.heating_unavailable_period		Heating unavailable period.
out.hot_water.clothes_washer.gal	gal	Hot water consumed by clothes washer
out.hot_water.dishwasher.gal	gal	Hot water consumed by dishwasher
out.hot_water.distribution_waste.gal	gal	Hot water consumed by water distribution system (water remaining in the pipe)
out.hot_water.fixtures.gal	gal	Hot water consumed by showers, sinks, and baths
out.params.size_water_heater..gal	gal	Size of water heater
out.load.cooling.energy_delivered..kbtu	kbtu	Total energy delivered by cooling system includes HVAC distribution losses
out.load.cooling.peak..kbtu_per_hr	kbtu/hr	Maximum cooling load delivered by cooling system includes HVAC distribution losses
out.load.heating.energy_delivered..kbtu	kbtu	Total energy delivered by heating system includes HVAC distribution losses

Table 234. Other ResStock results output field names, units, and descriptions (continued)

Field Name	Units	Field Description
out.load.heating.peak..kbtu_per_hr	kbtu/hr	Maximum heating energy delivered by heating system includes HVAC distribution losses over a 60 min time period
out.load.hot_water.energy_delivered..kbtu	kbtu	Total energy delivered by hot water system includes contributions by desuperheaters or solar thermal systems
out.load.hot_water.energy_solar_thermal..kbtu	kbtu	Total energy delivered by solar hot water system
out.load.hot_water.energy_tank_losses..kbtu	kbtu	Total energy lost by hot water system tanks
out.unmet_hours.cooling..hr	hr	Number of hours where the cooling setpoint is not maintained
out.unmet_hours.heating..hr	hr	Number of hours where the heating setpoint is not maintained
out.unmet_hours.ev_driving..hr	hr	Number of EV driving that cannot be achieved due to lack of charge
weight	n/a	the number of housing units the sample represents

For several of the outputs above, there is an associated savings or reduction column.

10 Public Data Access

ResStock results are publicly available for multiple weather years (generally 2018 and TMY) and a variety of upgrades in different formats to meet the various needs of decision makers and others who wish to make use of them. Not all runs that have some publicly available results are available in all formats.

10.1 Open Energy Data Initiative

Since 2021, all ResStock data releases have included the publication of results in an Open Energy Data Initiative (OEDI) data lake. Our output typically includes the following, with minor variations from dataset to dataset:

- The timeseries results aggregated by state, ISO/RTO region, Building America climate zone, and ASHRAE/IECC climate zone, in .csv format
- The individual housing unit sample model timeseries results, in .parquet format
- The baseline ResStock characteristics for each individual housing unit sample model, in both .csv and .parquet formats
- The full-year (annual) results for each housing unit sample model, in both .csv and .parquet formats
- The building energy models used in the run, in either .idf, .osm, or .xml format
- The schedule files for each housing unit sample used in running the models
- Select fields of the weather data (e.g., 2024.2) that is associated with the model run
- Data dictionaries
- Documentation containing details of the ResStock run and upgrade measures.

Results on OEDI include energy consumption for electricity, natural gas, propane, and fuel oil, and are available for the baseline and for each upgrade measure package. In many datasets, results also include some or all of hot water consumption, CO_2 equivalent emissions impacts, utility bill impacts, heating and cooling load, peak energy consumption, cost multipliers, energy savings, zone temperature data, unmet heating and cooling hours, and energy burden. Typically we convert the field names and units from ResStock's raw outputs before publishing data. We publish all energy consumption in kWh (even for direct on-site use of natural gas, propane, and fuel oil for equal comparison), and emissions in kg CO_2e.

10.2 Web-Based Visualization Platform

Portions of our datasets are available on a web-based visualization platform suite that pulls data directly from the OEDI data lake. Detailed examples, tutorials, and videos for using the data viewer are available on the ResStock website, but here we provide an overview of the capabilities.

The headline element is the timeseries data viewer, which allows the user to see total aggregated ResStock timeseries results in the browser. Seven data customization options are currently visible in the timeseries data viewer.

1. *Fuel type*: allows the user to choose which fuel consumption type to show (for example, to choose to view only electricity consumption results).
2. *Upgrade*: allows the user to choose which measure or measure package to view results from, when looking at a dataset that has measure packages in addition to the baseline data. For example, from the ResStock 2022.1 dataset, a user might choose to view results from the "heat pump water heaters" model upgrade package.
3. *Timeseries aggregation type*: four options are available.
    - *sum* is the current default. It shows the total energy consumption for all buildings that meet the current filter criteria across all the occurrences of the given time step within the selected month(s). For example, in a day timeseries range for a specific state for the month of July, the 7–7:15 AM time step shows the sum of all energy consumption statewide between 7 and 7:15 AM in July, from buildings that meet the filter criteria. The value in that timestamp would be approximately 1/96th of the total statewide energy consumption in that month in that sector.

  - *average* is the option that has the most uses. It shows the total energy consumption for all buildings that meet the filter criteria, averaged across all the occurrences of the given time step within the selected month(s). For example, in a day timeseries range for a specific state for the month of July, the 7–7:15 AM hour time step shows the average statewide energy consumption between 7 and 7:15 AM in July, from buildings that meet the filter criteria. The *average* aggregation provides a view of the average day of total energy consumption in the state.
  - *peak_day* shows results for the day with the highest single-hour (peak) energy consumption. It is only available when the month constraints are not used.
  - *min_peak_day* shows results for the day with the lowest single-hour energy consumption. It is only available when the month constraints are not used.

4. *Timeseries range*: three options are available.
   - *day* shows 24 hours of results at a 15-minute time resolution
   - *week* shows 7 days of results at an hourly time resolution
   - *year* shows 365 days of results at a daily time resolution.
5. *Month constraints*: sets which months of data are included in the view.
6. *Add Filters*: allows the user to reduce the number of housing unit samples used to generate the results by selecting which characteristic values to include, for each of the 100+ characteristics included in each dataset.
7. *More Locations*: allows the user to combine multiple locations into one set of results.

The web-based visualization platform functions as a custom aggregation tool as well. Any set of results generated using the "Add Filters" and "More Locations" options can be downloaded using the "export csv—15 minute resolution" option. This means any user can download aggregated results from any subset of the dataset that can be created using these data customization options. For example, a user could download aggregate results for a specific upgrade for single-family detached and single-family attached homes in Maryland, Delaware, and New Jersey that currently have electric heating. Generating these results would otherwise require a user to use their own AWS account or similar big data support service. These results include energy consumption at 15-minute increments in both the baseline and upgrade. They do not include other outputs such as energy bills, emissions, or energy burden.

An end-use annual results viewer and a histogram viewer are also currently available on the data viewer website. A building characteristics viewer was available for several years but has not been supported more recently. All of the information in these portions of the web-based data viewer is also accessible in Excel-friendly format from the OEDI data.

10.3 BuildStock Query

The ResStock team has created the BuildStockQuery Python library designed to simplify and streamline the process of querying massive, terabyte-scale datasets generated by ResStock and ComStock. It is available for public use but does require the user to have access to connect their own AWS Athena account to pay for the queries. It offers an Object-Oriented Programming (OOP) interface to the ResStock datasets, allowing users to more easily perform common queries and receive results in pandas DataFrame format, abstracting away the need for complex SQL queries. By initializing a query object with the pertinent Athena database and table names, users can easily specify queries. For example, to extract timeseries electricity for a specific end use for a given state, grouped by building types. More information is available in the wiki as well as a set of video tutorials on the use of BuildStockQuery.

10.4 Dashboards

The ResStock team currently hosts a Tableau Public site with Tableau dashboards that allow users to interactively view certain portions of results from specific ResStock projects. The two most popular are the *State Level Residential Building Stock and Energy Efficiency & Electrification Packages Analysis* dashboard, which presents state-level full-year results from the 2022.1 data release (Present et al. 2022), and the *US Building Typology Segmentation Residential* dashboard, which presents data from the 2022 U.S. Building Stock Characterization Study by Reyna et al. (2024), which used data from ResStock 2021.1 (Wilson et al. 2022).

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