OpenStudio-HPXML Documentation

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CHAPTER 1

Introduction

The OpenStudio-HPXML repository consists of residential OpenStudio measures that handle HPXML files.

1.1 Measures

This repository contains two OpenStudio measures:

1. `HPXMLtoOpenStudio`: A measure that translates an HPXML file to an OpenStudio model.
2. `SimulationOutputReport`: A reporting measure that generates a variety of annual/timeseries outputs for a residential HPXML-based model.

1.2 Modeling Capabilities

The OpenStudio-HPXML workflow can accommodate the following building features/technologies:

- Enclosure
  - Attics
    - Vented
    - Unvented
    - Conditioned
    - Radiant Barriers
  - Foundations
    - Slab
    - Unconditioned Basement
    - Conditioned Basement

    * Vented Crawlspace
    * Unvented Crawlspace
    * Ambient
  - Garages
  - Windows & Overhangs
  - Skylights
  - Doors
- HVAC
  - Heating Systems
    * Electric Resistance
    * Central/Wall/Floor Furnaces
    * Stoves, Portable/Fixed Heaters
    * Boilers
    * Fireplaces
  - Cooling Systems
    * Central/Room Air Conditioners
    * Evaporative Coolers
    * Mini Split Air Conditioners
    * Chillers
    * Cooling Towers
  - Heat Pumps
    * Air Source Heat Pumps
    * Mini Split Heat Pumps
    * Ground Source Heat Pumps
    * Dual-Fuel Heat Pumps
    * Water Loop Heat Pumps
  - Thermostat Setpoints
  - Ducts
- Water Heating
  - Water Heaters
    * Storage Tank
    * Instantaneous Tankless
    * Heat Pump Water Heater
    * Indirect Water Heater (Combination Boiler)
    * Tankless Coil (Combination Boiler)
  - Solar Hot Water

    - Desuperheaters
    - Hot Water Distribution
        * Recirculation
    - Drain Water Heat Recovery
    - Hot Water Fixtures
- Mechanical Ventilation
    - Exhaust Only
    - Supply Only
    - Balanced
    - Energy Recovery Ventilator
    - Heat Recovery Ventilator
    - Central Fan Integrated Supply
    - Shared Systems w/ Recirculation and/or Preconditioning
- Kitchen/Bath Fans
- Whole House Fan
- Photovoltaics
- Appliances
    - Clothes Washer
    - Clothes Dryer
    - Dishwasher
    - Refrigerator
    - Cooking Range/Oven
- Dehumidifiers
- Lighting
- Ceiling Fans
- Pool/Hot Tub
- Plug/Fuel Loads

1.3 Scope (Dwelling Units)

The OpenStudio-HPXML workflow is intended to be used to model individual residential dwelling units – either a single-family detached (SFD) building, or a single unit of a single-family attached (SFA) or multifamily (MF) building. This approach was taken because:

- It is required/desired for certain projects.
- It improves runtime speed by being able to simulate individual units in parallel (as opposed to simulating the entire building).
- It doesn't necessarily preclude the possibility of running a single integrated EnergyPlus simulation.

To model units of SFA/MF buildings, current capabilities include:

- Defining surfaces adjacent to generic SFA/MF spaces (e.g., “other housing unit” or “other multifamily buffer space”).
- Locating various building components (e.g., ducts, water heaters, appliances) in these SFA/MF spaces.
- Defining shared systems (HVAC, water heating, mechanical ventilation, etc.) by approximating the energy use attributed to the unit.

Note that only the energy use attributed to each dwelling unit is calculated. Other OpenStudio capabilities should be used to supplement this workflow if the energy use of non-residential dwelling spaces (e.g., gyms, elevators, corridors, etc.) are of interest.

For situations where more complex, integrated modeling is required, it is possible to merge multiple OpenStudio models together into a single model, such that one could merge all residential OSMs together and potentially combine it with a commercial OSM. That capability is outside the scope of this project.

1.4 Accuracy vs Speed

The EnergyPlus simulation engine is like a Swiss army knife. There are often multiple models available for the same building technology with varying trade-offs between accuracy and speed. This workflow standardizes the use of EnergyPlus (e.g., the choice of models appropriate for residential buildings) to provide a fast and easy to use solution.

The workflow is continuously being evaluated for ways to reduce runtime without significant impact on accuracy. End-to-end simulations typically run in 3-10 seconds, depending on complexity, computer platform and speed, etc.

There are additional ways that software developers using this workflow can reduce runtime:

- Run on Linux/Mac platform, which is significantly faster by taking advantage of the POSIX fork call.
- Do not use the `--hourly` flag unless hourly output is required. If required, limit requests to hourly variables of interest.
- Run on computing environments with 1) fast CPUs, 2) sufficient memory, and 3) enough processors to allow all simulations to run in parallel.

1.5 License

This project is available under a BSD-3-like license, which is a free, open-source, and permissive license. For more information, check out the license file.

CHAPTER 2

Getting Started

2.1 Setup

To get started:

1. Download OpenStudio 3.1.0 and install the Command Line Interface/EnergyPlus components, or use the nrel/openstudio docker image.
2. Download the latest release.

2.2 Running

To programatically run simulations, it's recommended to use the OpenStudio Command Line Interface. Two general approaches (basic and advanced) for running via the CLI are described below. The OpenStudio measures can also be run from user interfaces (e.g., the OpenStudio Application or OpenStudio Parametric Analysis Tool (PAT)).

Note: If the `openstudio` command is not found, it's because the executable is not in your PATH. Either add the executable to your PATH or point directly to the executable found in the openstudio-X.X.X/bin directory.

2.2.1 Basic Run

The simplest and fastest method is to call the OpenStudio CLI with the provided `workflow/run_simulation.rb` script.

For example: `openstudio workflow/run_simulation.rb -x workflow/sample_files/base.xml`

This will create a "run" directory with all input/output files. By default it will be found at the same location as the input HPXML file.

Run `openstudio workflow/run_simulation.rb -h` to see all available commands/arguments.

2.2.2 Advanced Run

If additional flexibility is desired (e.g., specifying individual measure arguments, including additional OpenStudio measures to run alongside this measure in a workflow, etc.), create an OpenStudio Workflow (OSW) file. The OSW is a JSON file that will specify all the OpenStudio measures (and their arguments) to be run sequentially. A template OSW that simply runs the HPXMLtoOpenStudio and SimulationOutputReport measures on the `workflow/sample_files/base.xml` file can be found at `workflow/template.osw`.

For example: `openstudio run -w workflow/template.osw`

This will create a "run" directory with all input/output files. By default it will be found at the same location as the OSW file.

2.2.3 Outputs

In addition to the standard EnergyPlus outputs found in the run directory, a variety of high-level annual outputs are conveniently reported in the resulting `run/results_annual.csv` file.

Timeseries outputs can also be requested using either the Basic or Advanced approaches. When requested, timeseries outputs will be found in the `run/results_timeseries.csv` file.

See the *SimulationOutputReport Measure* section for a description of all available outputs available.

CHAPTER 3

HPXMLtoOpenStudio Measure

3.1 Introduction

The HPXMLtoOpenStudio measure requires a building description in an HPXML file format. HPXML is an open data standard for collecting and transferring home energy data. Using HPXML files reduces the complexity and effort for software developers to leverage the EnergyPlus simulation engine.

3.2 HPXML Inputs

HPXML is an flexible and extensible format, where nearly all elements in the schema are optional and custom elements can be included. Because of this, a stricter set of requirements for the HPXML file have been developed for purposes of running EnergyPlus simulations.

HPXML files submitted to OpenStudio-HPXML should undergo a two step validation process:

1. Validation against the HPXML Schema

   The HPXML XSD Schema can be found at `HPXMLtoOpenStudio/resources/HPXML.xsd`. It should be used by the software developer to validate their HPXML file prior to running the simulation. XSD Schemas are used to validate what elements/attributes/enumerations are available, data types for elements/attributes, the number/order of children elements, etc.

   OpenStudio-HPXML **does not** validate the HPXML file against the XSD Schema and assumes the file submitted is valid. However, OpenStudio-HPXML does automatically check for valid data types (e.g., integer vs string), enumeration choices, and numeric values within min/max.

2. Validation using Schematron

   The Schematron document for the EnergyPlus use case can be found at `HPXMLtoOpenStudio/resources/EPvalidator.xml`. Schematron is a rule-based validation language, expressed in XML using XPath expressions, for validating the presence or absence of inputs in XML files. As opposed to an XSD Schema, a Schematron document validates constraints and requirements based on conditionals and other logical statements. For example, if an element is specified with a particular value, the applicable enumerations of another element may change.

OpenStudio-HPXML **automatically validates** the HPXML file against the Schematron document and reports any validation errors, but software developers may find it beneficial to also integrate Schematron validation into their software.

Important: Usage of both validation approaches (XSD and Schematron) is recommended for developers actively working on creating HPXML files for EnergyPlus simulations:

- Validation against XSD for general correctness and usage of HPXML
- Validation against Schematron for understanding XML document requirements specific to running EnergyPlus

3.2.1 Input Defaults

An increasing number of elements in the HPXML file are being made optional with "smart" defaults. Default values, equations, and logic are described throughout this documentation.

Most defaults can also be seen by using the `debug` argument/flag when running the workflow on an actual HPXML file. This will create a new HPXML file (`in.xml` in the run directory) where additional fields are populated for inspection.

For example, suppose a HPXML file has a window defined as follows:

```xml
<Window>
  <SystemIdentifier id='Window'/>
  <Area>108.0</Area>
  <Azimuth>0</Azimuth>
  <UFactor>0.33</UFactor>
  <SHGC>0.45</SHGC>
  <AttachedToWall idref='Wall'/>
</Window>
```

In the `in.xml` file, the window would have additional elements like so:

```xml
<Window>
  <SystemIdentifier id='Window'/>
  <Area>108.0</Area>
  <Azimuth>0</Azimuth>
  <UFactor>0.33</UFactor>
  <SHGC>0.45</SHGC>
  <InteriorShading>
    <SystemIdentifier id='WindowInteriorShading'/>
    <SummerShadingCoefficient>0.7</SummerShadingCoefficient>
    <WinterShadingCoefficient>0.85</WinterShadingCoefficient>
  </InteriorShading>
  <FractionOperable>0.67</FractionOperable>
  <AttachedToWall idref='Wall'/>
</Window>
```

Warning: The OpenStudio-HPXML workflow generally treats missing HPXML elements differently than elements provided but without additional detail. For example, if an HPXML file has no `Refrigerator` element defined, it will be interpreted as a building that has no refrigerator and modeled this way. On the other hand, if there is a `Refrigerator` element defined but no elements within, it is interpreted as a building that has a refrigerator, but no information about the refrigerator is known. In this case, its details (e.g., location, energy use) will be defaulted in the model.

3.3 HPXML Software Info

High-level simulation inputs are entered in HPXML's /HPXML/SoftwareInfo. Current inputs include simulation controls and HVAC sizing controls.

3.3.1 HPXML Simulation Control

EnergyPlus simulation controls can be entered in extension/SimulationControl.

The simulation timestep can be optionally provided as Timestep, where the value is in minutes and must be a divisor of 60. If not provided, the default value of 60 (i.e., 1 hour) is used.

The simulation run period can be optionally specified with BeginMonth/BeginDayOfMonth and/or EndMonth/EndDayOfMonth. The BeginMonth/BeginDayOfMonth provided must occur before EndMonth/EndDayOfMonth provided (e.g., a run period from 10/1 to 3/31 is invalid). If not provided, default values of January 1st and December 31st will be used.

The simulation run period calendar year can be optionally specified with CalendarYear. The calendar year is used to determine the simulation start day of week. If the EPW weather file is TMY (Typical Meteorological Year), the default value of 2007 will be used if not specified. If the EPW weather file is AMY (Actual Meteorological Year), the AMY year will be used regardless of what is specified.

Whether to apply daylight saving time can be optionally denoted with DaylightSaving/Enabled. If either DaylightSaving or DaylightSaving/Enabled is not provided, DaylightSaving/Enabled will default to true. If daylight saving is enabled, the daylight saving period can be optionally specified with DaylightSaving/BeginMonth, DaylightSaving/BeginDayOfMonth, DaylightSaving/EndMonth, and DaylightSaving/EndDayOfMonth. If not specified, dates will be defined according to the EPW weather file header; if not available there, default values of March 12 and November 5 will be used.

3.3.2 HPXML HVAC Sizing Control

HVAC equipment sizing controls can be entered in extension/HVACSizingControl.

An optional AllowIncreasedFixedCapacities element can be provided to describe how HVAC equipment with fixed capacities are handled. If false, the user-specified fixed capacity will be used. If true, the maximum of the user-specified fixed capacity and the heating/cooling design load will be used to reduce potential for unmet loads. If not provided, the default value of false is used.

An optional UseMaxLoadForHeatPumps element can be provided to describe how autosized heat pumps are handled. If true, heat pumps are sized based on the maximum of heating and cooling design loads. If false, heat pumps are sized per ACCA Manual J/S based on cooling design loads with some oversizing allowances for heating design loads. If not provided, the default value of true is used.

3.4 HPXML Building Details

The building description is entered in HPXML's /HPXML/Building/BuildingDetails.

3.5 HPXML Building Summary

This section describes elements specified in HPXML's BuildingSummary. These elements include Site, BuildingOccupancy, and BuildingConstruction.

3.5.1 HPXML Site

The `Site` element is used to describe the terrain and local shelter conditions as well as the presence of neighbors.

The terrain surrounding the building can be optionally entered as `Site/SiteType`; if not provided, it is assumed to be "suburban".

The local shelter coefficient can be entered as `Site/extension/ShelterCoefficient`. The shelter coefficient is defined by the AIM-2 infiltration model to account for nearby buildings, trees and obstructions. If not provided, the value of 0.5 will be assumed.

Shelter Coefficient	Description
1.0	No obstructions or local shielding
0.9	Light local shielding with few obstructions within two building heights
0.7	Local shielding with many large obstructions within two building heights
0.5	Heavily shielded, many large obstructions within one building height
0.3	Complete shielding with large buildings immediately adjacent

Shading due to neighboring buildings can be defined inside an `extension/Neighbors` element. Each `Neighbors/NeighborBuilding` element is required to have an `Azimuth` and `Distance` from the house. A `Height` is also optionally allowed; if not provided, the neighboring building is assumed to have the same height as the house.

3.5.2 HPXML Building Occupancy

The `BuildingOccupancy` element is used to describe the occupants.

The number of occupants can be optionally provided as `NumberofResidents`; if not provided, it is assumed that the number of occupants equal the number of bedrooms.

Note: Most occupancy assumptions (e.g., plug loads, appliance usage, hot water usage, etc.) are based on the number of bedrooms. The number of residents is solely used to determine heat gains from the occupants themselves.

3.5.3 HPXML Building Construction

The `BuildingConstruction` element is used to describe high-level building information. Fields include:

- `ResidentialFacilityType`: "single-family detached", "single-family attached", "apartment unit", or "manufactured home"
- `NumberofConditionedFloors`
- `NumberofConditionedFloorsAboveGrade`: Note that this should include a walkout basement if present.
- `NumberofBedrooms`
- `NumberofBathrooms`: Optional. If not provided, it is calculated as $\frac{NumberofBedrooms}{2} + 0.5$ based on the Building America House Simulation Protocols.
- `ConditionedFloorArea`
- `ConditionedBuildingVolume` or `AverageCeilingHeight`

- extension/HasFlueOrChimney: Optional. Specifies whether there is a flue (associated with heating system or water heater) or chimney. If not provided, it is assumed to be true if any of the following conditions are met:
  - heating system is non-electric Furnace, Boiler, WallFurnace, FloorFurnace, Stove, or FixedHeater and AFUE/Percent is less than 0.89
  - heating system is non-electric Fireplace
  - water heater is non-electric with energy factor (or equivalent calculated from uniform energy factor) less than 0.63

3.6 HPXML Weather Station

The ClimateandRiskZones/WeatherStation/extension/EPWFilePath element specifies the path to the EnergyPlus weather file (EPW) to be used by the simulation. The full set of U.S. TMY3 weather files can be downloaded here.

3.7 HPXML Enclosure

This section describes elements specified in HPXML's Enclosure.

All surfaces that bound different space types in the building (i.e., not just thermal boundary surfaces) must be specified in the HPXML file. For example, an attached garage would generally be defined by walls adjacent to conditioned space, walls adjacent to outdoors, a slab, and a roof or ceiling. For software tools that do not collect sufficient inputs for every required surface, the software developers will need to make assumptions about these surfaces or collect additional input.

The space types used in the HPXML building description are:

Space Type	Description	Temperature	Building Type
living space	Above-grade conditioned floor area	EnergyPlus calculation	Any
attic - vented		EnergyPlus calculation	Any
attic - unvented		EnergyPlus calculation	Any
basement - conditioned	Below-grade conditioned floor area	EnergyPlus calculation	Any
basement - unconditioned		EnergyPlus calculation	Any
crawlspace - vented		EnergyPlus calculation	Any
crawlspace - unvented		EnergyPlus calculation	Any
garage	Single-family garage (not shared parking garage)	EnergyPlus calculation	Any
other housing unit	E.g., conditioned adjacent unit or corridor	Same as conditioned space	Attached/Multifamily only
other heated space	E.g., shared laundry/equipment space	Average of conditioned space and outside; minimum of 68F	Attached/Multifamily only
other multifamily buffer space	E.g., enclosed unconditioned stairwell	Average of conditioned space and outside; minimum of 50F	Attached/Multifamily only
other non-freezing space	E.g., shared parking garage ceiling	Floats with outside; minimum of 40F	Attached/Multifamily only

Interior partition surfaces (e.g., walls between rooms inside conditioned space, or the floor between two conditioned stories) can be excluded.

For Attached/Multifamily buildings, surfaces between unconditioned space and the neigboring unit's same unconditioned space should set `InteriorAdjacentTo` and `ExteriorAdjacentTo` to the same value. For example, a foundation wall between the unit's vented crawlspace and the neighboring unit's vented crawlspace would use `InteriorAdjacentTo="crawlspace - vented"` and `ExteriorAdjacentTo="crawlspace - vented"`.

> **Warning:** It is the software tool's responsibility to provide the appropriate building surfaces. While some error-checking is in place, it is not possible to know whether some surfaces are incorrectly missing.

Also note that wall and roof surfaces do not require an azimuth to be specified. Rather, only the windows/skylights themselves require an azimuth. Thus, software tools can choose to use a single wall (or roof) surface to represent multiple wall (or roof) surfaces for the entire building if all their other properties (construction type, interior/exterior adjacency, etc.) are identical.

3.7.1 HPXML Air Infiltration

Building air leakage is entered using `Enclosure/AirInfiltration/AirInfiltrationMeasurement`. Air leakage can be provided in one of three ways:

1. nACH (natural air changes per hour): Use `BuildingAirLeakage/UnitofMeasure='ACHnatural'`.

2. ACH (air changes per hour at user-specified pressure): Use `BuildingAirLeakage/UnitofMeasure='ACH'` and `HousePressure`. Pressure is typically 50 Pa.
3. CFM (cubic feet per minute at user-specified pressure): Use `BuildingAirLeakage/UnitofMeasure='CFM'` and `HousePressure`. Pressure is typically 50 Pa.

In addition, the building's volume associated with the air leakage measurement can be provided in HPXML's `AirInfiltrationMeasurement/InfiltrationVolume`. If not provided, the infiltration volume is assumed to be equal to the conditioned building volume.

3.7.2 HPXML Attics/Foundations

The ventilation rate for vented attics (or vented crawlspaces) can be specified using an `Attic` (or `Foundation`) element. First, define the `AtticType` as `Attic[Vented='true']` (or `FoundationType` as `Crawlspace[Vented='true']`). Then specify the specific leakage area (SLA) using the `VentilationRate[UnitofMeasure='SLA']/Value` element. For vented attics, the natural air changes per hour (nACH) can instead be specified using `UnitofMeasure='ACHnatural'`. If the ventilation rate is not provided, default values of SLA=1/300 for vented attics and SLA=1/150 for vented crawlspaces will be used based on ANSI/RESNET/ICC 301-2019.

3.7.3 HPXML Roofs

Pitched or flat roof surfaces that are exposed to ambient conditions should be specified as an `Enclosure/Roofs/Roof`. For a multifamily building where the dwelling unit has another dwelling unit above it, the surface between the two dwelling units should be considered a `FrameFloor` and not a `Roof`.

Roofs are defined by their `Area`, `Pitch`, `Insulation/AssemblyEffectiveRValue`, `SolarAbsorptance`, and `Emittance`.

Roofs must have either `RoofColor` and/or `SolarAbsorptance` defined. If `RoofColor` or `SolarAbsorptance` is not provided, it is defaulted based on the mapping below:

RoofColor	RoofMaterial	SolarAbsorptance
dark	asphalt or fiberglass shingles, wood shingles or shakes	0.92
medium dark	asphalt or fiberglass shingles, wood shingles or shakes	0.89
medium	asphalt or fiberglass shingles, wood shingles or shakes	0.85
light	asphalt or fiberglass shingles, wood shingles or shakes	0.75
reflective	asphalt or fiberglass shingles, wood shingles or shakes	0.50
dark	slate or tile shingles, metal surfacing	0.90
medium dark	slate or tile shingles, metal surfacing	0.83
medium	slate or tile shingles, metal surfacing	0.75
light	slate or tile shingles, metal surfacing	0.60
reflective	slate or tile shingles, metal surfacing	0.30

Roofs can also have optional elements provided for `RadiantBarrier and ``RoofType`. If `RadiantBarrier` is not provided, it is defaulted to not present; if it is provided, `RadiantBarrierGrade` must also be provided. If `RoofType` is not provided, it is defaulted to "asphalt or fiberglass shingles".

3.7.4 HPXML Rim Joists

Rim joists, the perimeter of floor joists typically found between stories of a building or on top of a foundation wall, are specified as an `Enclosure/RimJoists/RimJoist`. The `InteriorAdjacentTo` element should typically be "living space" for rim joists between stories of a building and "basement - conditioned", "basement - unconditioned", "crawlspace - vented", or "crawlspace - unvented" for rim joists on top of a foundation wall.

Rim joists are defined by their `Area` and `Insulation/AssemblyEffectiveRValue`.

Rim joists must have either `Color` and/or `SolarAbsorptance` defined. If `Color` or `SolarAbsorptance` is not provided, it is defaulted based on the mapping below:

Color	SolarAbsorptance
dark	0.95
medium dark	0.85
medium	0.70
light	0.50
reflective	0.30

Rim joists can have an optional element provided for `Siding`; if not provided, it defaults to "wood siding".

3.7.5 HPXML Walls

Any wall that has no contact with the ground and bounds a space type should be specified as an `Enclosure/Walls/Wall`.

Walls are defined by their `Area` and `Insulation/AssemblyEffectiveRValue`. The choice of `WallType` has a secondary effect on heat transfer in that it informs the assumption of wall thermal mass.

Walls must have either `Color` and/or `SolarAbsorptance` defined. If `Color` or `SolarAbsorptance` is not provided, it is defaulted based on the mapping below:

Color	SolarAbsorptance
dark	0.95
medium dark	0.85
medium	0.70
light	0.50
reflective	0.30

Walls can have an optional element provided for `Siding`; if not provided, it defaults to "wood siding".

3.7.6 HPXML Foundation Walls

Any wall that is in contact with the ground should be specified as an `Enclosure/FoundationWalls/FoundationWall`. Other walls (e.g., wood framed walls) that are connected to a below-grade space but have no contact with the ground should be specified as `Walls` and not `FoundationWalls`.

Exterior foundation walls (i.e., those that fall along the perimeter of the building's footprint) should use "ground" for `ExteriorAdjacentTo` and the appropriate space type (e.g., "basement - unconditioned") for `InteriorAdjacentTo`.

Interior foundation walls should be specified with two appropriate space types (e.g., "crawlspace - vented" and "garage", or "basement - unconditioned" and "crawlspace - unvented") for `InteriorAdjacentTo` and `ExteriorAdjacentTo`. Interior foundation walls should never use "ground" for `ExteriorAdjacentTo` even if the foundation wall has some contact with the ground due to the difference in below-grade depths of the two adjacent space types.

Foundations must include a `Height` as well as a `DepthBelowGrade`. For exterior foundation walls, the depth below grade is relative to the ground plane. For interior foundation walls, the depth below grade **should not** be thought of as relative to the ground plane, but rather as the depth of foundation wall in contact with the ground. For example, an interior foundation wall between an 8 ft conditioned basement and a 3 ft crawlspace has a height of 8 ft and a depth below grade of 5 ft. Alternatively, an interior foundation wall between an 8 ft conditioned basement and an 8 ft unconditioned basement has a height of 8 ft and a depth below grade of 0 ft.

Foundation wall insulation can be described in two ways:

Option 1. Both interior and exterior continuous insulation layers with `NominalRValue`, `extension/DistanceToTopOfInsulation`, and `extension/DistanceToBottomOfInsulation`. Insulation layers are particularly useful for describing foundation wall insulation that doesn't span the entire height (e.g., 4 ft of insulation for an 8 ft conditioned basement). If there is not insulation on the interior and/or exterior of the foundation wall, the continuous insulation layer must still be provided – with the nominal R-value, etc., set to zero. When insulation is specified with option 1, it is modeled with a concrete wall (whose `Thickness` is provided) as well as air film resistances as appropriate.

Option 2. An `AssemblyEffectiveRValue`. The assembly effective R-value should include the concrete wall and an interior air film resistance. The exterior air film resistance (for any above-grade exposure) or any soil thermal resistance should **not** be included.

3.7.7 HPXML Frame Floors

Any horizontal floor/ceiling surface that is not in contact with the ground (Slab) nor adjacent to ambient conditions above (Roof) should be specified as an `Enclosure/FrameFloors/FrameFloor`.

Frame floors in an attached/multifamily building that are adjacent to "other housing unit", "other heated space", "other multifamily buffer space", or "other non-freezing space" must have the `extension/OtherSpaceAboveOrBelow` property set to signify whether the other space is "above" or "below".

Frame floors are primarily defined by their `Area` and `Insulation/AssemblyEffectiveRValue`.

3.7.8 HPXML Slabs

Any space type that borders the ground should include an `Enclosure/Slabs/Slab` surface with the appropriate `InteriorAdjacentTo`. This includes basements, crawlspaces (even when there are dirt floors – use zero for the `Thickness`), garages, and slab-on-grade foundations.

A primary input for a slab is its `ExposedPerimeter`. The exposed perimeter should include any slab length that falls along the perimeter of the building's footprint (i.e., is exposed to ambient conditions). So, a basement slab edge adjacent to a garage or crawlspace, for example, should not be included.

Vertical insulation adjacent to the slab can be described by a `PerimeterInsulation/Layer/NominalRValue` and a `PerimeterInsulationDepth`.

Horizontal insulation under the slab can be described by a `UnderSlabInsulation/Layer/NominalRValue`. The insulation can either have a fixed width (`UnderSlabInsulationWidth`) or can span the entire slab (`UnderSlabInsulationSpansEntireSlab`).

For foundation types without walls, the `DepthBelowGrade` element must be provided. For foundation types with walls, the `DepthBelowGrade` element is not used; instead the slab's position relative to grade is determined by the `FoundationWall/DepthBelowGrade` values.

3.7.9 HPXML Windows

Any window or glass door area should be specified as an `Enclosure/Windows/Window`.

Windows are defined by *full-assembly* NFRC `UFactor` and `SHGC`, as well as `Area`. Windows must reference a HPXML `Enclosures/Walls/Wall` element via the `AttachedToWall`. Windows must also have an `Azimuth` specified, even if the attached wall does not.

In addition, the summer/winter interior shading coefficients can be optionally entered as `InteriorShading/SummerShadingCoefficient` and `InteriorShading/WinterShadingCoefficient`. Note that a value of 0.7 indicates a 30% reduction in solar gains (i.e., 30% shading). If not provided, default values of 0.70 for summer and 0.85 for winter will be used based on ANSI/RESNET/ICC 301-2019.

Overhangs (e.g., a roof eave) can optionally be defined for a window by specifying a `Window/Overhangs` element. Overhangs are defined by the vertical distance between the overhang and the top of the window (`DistanceToTopOfWindow`), and the vertical distance between the overhang and the bottom of the window (`DistanceToBottomOfWindow`). The difference between these two values equals the height of the window.

Finally, windows can be optionally described with `FractionOperable`. The input should solely reflect whether the windows are operable (can be opened), not how they are used by the occupants. If a `Window` represents a single window, the value should be 0 or 1. If a `Window` represents multiple windows (e.g., 4), the value should be between 0 and 1 (e.g., 0, 0.25, 0.5, 0.75, or 1). If not provided, it is assumed that 67% of the windows are operable. The total open window area for natural ventilation is thus calculated using A) the fraction of windows that are operable, B) the assumption that 50% of the area of operable windows can be open, and C) the assumption that 20% of that openable area is actually opened by occupants whenever outdoor conditions are favorable for cooling.

3.7.10 HPXML Skylights

Any skylight should be specified as an `Enclosure/Skylights/Skylight`.

Skylights are defined by *full-assembly* NFRC `UFactor` and `SHGC`, as well as `Area`. Skylights must reference a HPXML `Enclosures/Roofs/Roof` element via the `AttachedToRoof`. Skylights must also have an `Azimuth` specified, even if the attached roof does not.

In addition, the summer/winter interior shading coefficients can be optionally entered as `InteriorShading/SummerShadingCoefficient` and `InteriorShading/WinterShadingCoefficient`. The summer interior shading coefficient must be less than or equal to the winter interior shading coefficient. Note that a value of 0.7 indicates a 30% reduction in solar gains (i.e., 30% shading). If not provided, default values of 1.0 for summer and 1.0 for winter will be used.

3.7.11 HPXML Doors

Any opaque doors should be specified as an `Enclosure/Doors/Door`.

Doors are defined by `RValue` and `Area`. Doors must reference a HPXML `Enclosures/Walls/Wall` element via the `AttachedToWall`. Doors must also have an `Azimuth` specified, even if the attached wall does not.

3.8 HPXML Systems

This section describes elements specified in HPXML's `Systems`.

If any HVAC systems are entered that provide heating (or cooling), the sum of all their `FractionHeatLoadServed` (or `FractionCoolLoadServed`) values must be less than or equal to 1. For example, a room air conditioner might be specified with `FractionCoolLoadServed` equal to 0.3 if it serves 30% of the home's conditioned floor area.

If any water heating systems are entered, the sum of all their `FractionDHWLoadServed` values must be equal to 1.

3.8.1 HPXML Heating Systems

Each heating system (other than heat pumps) should be entered as a `Systems/HVAC/HVACPlant/HeatingSystem`. Inputs including `HeatingSystemType` and `FractionHeatLoadServed` must be provided.

Depending on the type of heating system specified, additional elements are used:

HeatingSystemType	IsSharedSystem	DistributionSystem	HeatingSystemFuel	AnnualHeatingEfficiency	HeatingCapacity	extension/FanPowerWatts	extension/FanPowerWattsPerCFM
ElectricResistance			electricity	Percent	(optional)		
Furnace		AirDistribution or DSE	<any>	AFUE	(optional)		(optional)
WallFurnace			<any>	AFUE	(optional)	(optional)	
FloorFurnace			<any>	AFUE	(optional)	(optional)	
Boiler	false	HydronicDistribution or DSE	<any>	AFUE	(optional)		
Boiler	true	HydronicDistribution or HydronicAndAirDistribution	<any>	AFUE			
Stove			<any>	Percent	(optional)	(optional)	
PortableHeater			<any>	Percent	(optional)	(optional)	
FixedHeater			<any>	Percent	(optional)	(optional)	
Fireplace			<any>	Percent	(optional)	(optional)	

When `HeatingCapacity` is not provided; the system will be auto-sized via ACCA Manual J/S.

If the fan power is not provided (`extension/FanPowerWattsPerCFM` or `extension/FanPowerWatts` as appropriate), it will be defaulted as follows:

System Type	Fan Power
Furnace	0.5 W/cfm if AFUE <= 0.9, else 0.375 W/cfm
Stove	40 W
all others	0 W

For a furnace connected to an air conditioner, if fan powers are provided for both systems, they must be equal.

For boilers, the `ElectricAuxiliaryEnergy` element may be provided if available. For shared boilers (i.e., serving multiple dwelling units), the electric auxiliary energy can alternatively be calculated as follows per ANSI/RESNET/ICC 301-2019:

$$EAE = (\frac{SP}{N_{dweq}} + aux_{in}) \cdot HLH$$

where,

SP = Shared pump power [W], provided as `extension/SharedLoopWatts`

N_{dweq} = Number of units served by the shared system, provided as `NumberofUnitsServed`
aux_{in} = In-unit fan coil power [W], provided as `extension/FanCoilWatts`
HLH = Annual heating load hours

If electric auxiliary energy is not provided (nor calculated for shared boilers), it is defaulted per ANSI/RESNET/ICC 301-2019 as follows:

System Type	Electric Auxiliary Energy
Oil boiler	330
Gas boiler (in-unit)	170
Gas boiler (shared, w/ baseboard)	220
Gas boiler (shared, w/ water loop heat pump)	265
Gas boiler (shared, w/ fan coil)	438

For shared boilers connected to a water loop heat pump, the heat pump's heating COP must be provided as `extension/WaterLoopHeatPump/AnnualHeatingEfficiency[Units="COP"]/Value`.

3.8.2 HPXML Cooling Systems

Each cooling system (other than heat pumps) should be entered as a `Systems/HVAC/HVACPlant/CoolingSystem`. Inputs including `CoolingSystemType` and `FractionCoolLoadServed` must be provided.

Depending on the type of cooling system specified, additional elements are used:

CoolingSystemType	IsSharedSystem	DistributionSystem	CoolingSystemFuel	AnnualCoolingEfficiency	SensibleHeatFraction	CoolingCapacity	extension/FanPowerWattsPerCFM
central air conditioner		AirDistribution or DSE	electricity	SEER	(optional)	(optional)	(optional)
room air conditioner			electricity	EER	(optional)	(optional)	
evaporative cooler		AirDistribution or DSE (optional)	electricity				(optional)
mini-split		AirDistribution or DSE (optional)	electricity	SEER	(optional)	(optional)	(optional)
chiller	true	HydronicDistribution or HydronicAndAirDistribution	electricity	kW/ton		(required)	
cooling tower	true	HydronicAndAirDistribution	electricity				

When `CoolingCapacity` is not provided, the system will be auto-sized via ACCA Manual J/S.

Central air conditioners can also have the `CompressorType` specified; if not provided, it is assumed as follows:

- "single stage": SEER <= 15
- "two stage": 15 < SEER <= 21

- "variable speed": SEER > 21

If the fan power is not provided (extension/FanPowerWattsPerCFM), it will be defaulted as follows:

System Type	Fan Power
central air conditioner	Attached furnace W/cfm if available, else 0.5 W/cfm if SEER <= 13.5, else 0.375 W/cfm
evaporative cooler	MIN(2.79 * cfm^-0.29, 0.6) W/cfm
mini-split	0.07 W/cfm if ductless, else 0.18 W/cfm

For an air conditioner connected to a furnace, if fan powers are provided for both systems they must be equal.

Shared chillers (i.e., serving multiple dwelling units) are modeled with a SEER equivalent using the following equation from ANSI/RESNET/ICC 301-2019:

$$SEER_{eq} = \frac{(Cap - (aux \cdot 3.41)) - (aux_{dweq} \cdot 3.41 \cdot N_{dweq})}{(Input \cdot aux) + (aux_{dweq} \cdot N_{dweq})}$$

where,

Cap = Chiller system output [Btu/hour], provided as CoolingCapacity

aux = Total of the pumping and fan power serving the system [W], provided as extension/SharedLoopWatts

aux_{dweq} = Total of the in-unit cooling equipment power serving the unit; for example, includes all power to run a Water Loop Heat Pump within the unit, not just air handler power [W], provided as extension/FanCoilWatts for fan coils, or calculated as extension/WaterLoopHeatPump/CoolingCapacity divided by extension/WaterLoopHeatPump/AnnualCoolingEfficiency[Units="EER"]/Value for cooling towers, or zero for baseboard/radiators

$Input$ = Chiller system power [W], calculated using AnnualCoolingEfficiency[Units="kW/ton"]/Value

N_{dweq} = Number of units served by the shared system, provided as NumberofUnitsServed

Shared cooling towers with water loop heat pumps are modeled with a SEER equivalent using the following equation from ANSI/RESNET/ICC 301-2019:

$$SEER_{eq} = \frac{WLHP_{cap} - \frac{aux \cdot 3.41}{N_{dweq}}}{Input + \frac{aux}{N_{dweq}}}$$

where,

$WLHP_{cap}$ = WLHP cooling capacity [Btu/hr], provided as extension/WaterLoopHeatPump/CoolingCapacity

aux = Total of the pumping and fan power serving the system [W], provided as extension/SharedLoopWatts

N_{dweq} = Number of units served by the shared system, provided as NumberofUnitsServed

$Input$ = WLHP system power [W], calculated as extension/WaterLoopHeatPump/CoolingCapacity divided by extension/WaterLoopHeatPump/AnnualCoolingEfficiency[Units="EER"]/Value

3.8.3 HPXML Heat Pumps

Each heat pump should be entered as a Systems/HVAC/HVACPlant/HeatPump. Inputs including HeatPumpType, FractionHeatLoadServed, and FractionCoolLoadServed must be provided. Note that heat pumps are allowed to provide only heating (FractionCoolLoadServed = 0) or cooling (FractionHeatLoadServed = 0) if appropriate.

Depending on the type of heat pump specified, additional elements are used:

HeatPumpType	IsSharedSystem	DistributionSystem	HeatPumpFuel	AnnualCoolingEfficiency	AnnualHeatingEfficiency	CoolingSensibleHeatFraction	HeatingCapacity17F	extension/FanPowerWattsPerCFM	extension/PumpPowerWattsPerTon
air-to-air		AirDistribution or DSE	electricity	SEER	HSPF	(optional)	(optional)	(optional)	
mini-split		AirDistribution or DSE (optional)	electricity	SEER	HSPF	(optional)	(optional)	(optional)	
ground-to-air	false	AirDistribution or DSE	electricity	EER	COP	(optional)		(optional)	(optional)
ground-to-air	true	AirDistribution or DSE	electricity	EER	COP	(optional)		(optional)	(optional)

When `HeatingCapacity` and `CoolingCapacity` are not provided, the system will be auto-sized via ACCA Manual J/S.

Air-to-air heat pumps can also have the `CompressorType` specified; if not provided, it is assumed as follows:

- "single stage": SEER <= 15
- "two stage": 15 < SEER <= 21
- "variable speed": SEER > 21

If the fan power is not provided (`extension/FanPowerWattsPerCFM`), it will be defaulted as follows:

System Type	Fan Power
air-to-air, ground-to-air	0.5 W/cfm if HSPF <= 8.75 W/cfm, else 0.375 W/cfm
mini-split	0.07 W/cfm if ductless, else 0.18 W/cfm

If the heat pump has backup heating, it can be specified with `BackupSystemFuel`, `BackupAnnualHeatingEfficiency`, and (optionally) `BackupHeatingCapacity`. If the heat pump has a switchover temperature (e.g., dual-fuel heat pump) where the heat pump stops operating and the backup heating system starts running, it can be specified with `BackupHeatingSwitchoverTemperature`. If `BackupHeatingSwitchoverTemperature` is not provided, the backup heating system will operate as needed when the heat pump has insufficient capacity.

If the pump power for ground-to-air heat pumps is not provided (`extension/PumpPowerWattsPerTon`), it will be defaulted as 30 W/ton of cooling capacity per ANSI/RESNET/ICC 301-2019 for a closed loop system

For multiple ground source heat pumps on a shared hydronic circulation loop (`IsSharedSystem="true"`), the loop's annual electric consumption is calculated using the following equation from ANSI/RESNET/ICC 301-2019:

$$Eae = \frac{SP}{N_{dweq}} \cdot 8.760$$

where,

SP = Shared pump power [W], provided as `extension/SharedLoopWatts`

N_{dweq} = Number of units served by the shared system, provided as `NumberofUnitsServed`

3.8.4 HPXML HVAC Control

A `Systems/HVAC/HVACControl` must be provided if any HVAC systems are specified. The heating setpoint (`SetpointTempHeatingSeason`) and cooling setpoint (`SetpointTempCoolingSeason`) are required elements.

If there is a heating setback, it is defined with:

- `SetbackTempHeatingSeason`: Temperature during heating setback
- `extension/SetbackStartHourHeating`: The start hour of the heating setback where 0=midnight and 12=noon
- `TotalSetbackHoursperWeekHeating`: The number of hours of heating setback per week

If there is a cooling setup, it is defined with:

- `SetupTempCoolingSeason`: Temperature during cooling setup
- `extension/SetupStartHourCooling`: The start hour of the cooling setup where 0=midnight and 12=noon
- `TotalSetupHoursperWeekCooling`: The number of hours of cooling setup per week

Finally, if there are sufficient ceiling fans present that result in a reduced cooling setpoint, this offset can be specified with `extension/CeilingFanSetpointTempCoolingSeasonOffset`.

3.8.5 HPXML HVAC Distribution

Each separate HVAC distribution system should be specified as a `Systems/HVAC/HVACDistribution`. The four types of HVAC distribution systems allowed are `AirDistribution`, `HydronicDistribution`, `HydronicAndAirDistribution`, and `DSE`. There should be at most one heating system and one cooling system attached to a distribution system. See the sections on Heating Systems, Cooling Systems, and Heat Pumps for information on which `DistributionSystemType` is allowed for which HVAC system. Also note that some HVAC systems (e.g., room air conditioners) are not allowed to be attached to a distribution system.

Air Distribution

`AirDistribution` systems are defined by:

- `ConditionedFloorAreaServed`
- Optional `NumberofReturnRegisters`. If not provided, one return register per conditioned floor will be assumed.
- Optional supply leakage to the outside in CFM25 or percent of airflow (`DuctLeakageMeasurement[DuctType='supply']/DuctLeakage/Value`)
- Optional return leakage to the outside in CFM25 or percent of airflow (`DuctLeakageMeasurement[DuctType='return']/DuctLeakage/Value`)
- Optional supply ducts (`Ducts[DuctType='supply']`)
- Optional return ducts (`Ducts[DuctType='return']`)

For each duct, `DuctInsulationRValue` must be provided. `DuctLocation` and `DuctSurfaceArea` can be optionally provided. The provided `DuctLocation` can be one of the following:

Location	Description	Temperature	Building Type	Default Priority
living space	Above-grade conditioned floor area	EnergyPlus calculation	Any	8
basement - conditioned	Below-grade conditioned floor area	EnergyPlus calculation	Any	1
basement - unconditioned		EnergyPlus calculation	Any	2
crawlspace - unvented		EnergyPlus calculation	Any	4
crawlspace - vented		EnergyPlus calculation	Any	3
attic - unvented		EnergyPlus calculation	Any	6
attic - vented		EnergyPlus calculation	Any	5
garage	Single-family garage (not shared parking garage)	EnergyPlus calculation	Any	7
outside		Outside	Any	
exterior wall		Average of conditioned space and outside	Any	
under slab		Ground	Any	
roof deck		Outside	Any	
other housing unit	E.g., conditioned adjacent unit or corridor	Same as conditioned space	Attached/Multifamily only	
other heated space	E.g., shared laundry/equipment space	Average of conditioned space and outside; minimum of 68F	Attached/Multifamily only	
other multifamily buffer space	E.g., enclosed unconditioned stairwell	Average of conditioned space and outside; minimum of 50F	Attached/Multifamily only	
other non-freezing space	E.g., shared parking garage ceiling	Floats with outside; minimum of 40F	Attached/Multifamily only	

If `DuctLocation` is not provided, the primary duct location will be chosen based on the presence of spaces and the "Default Priority" indicated above. For a 2+ story home, secondary ducts will also be located in the living space.

If `DuctSurfaceArea` is not provided, the total duct area will be calculated based on ANSI/ASHRAE Standard 152-2004:

Element Name	Default Value
DuctSurfaceArea (primary supply ducts)	$0.27 \cdot F_{out} \cdot CFA_{ServedByAirDistribution}$
DuctSurfaceArea (secondary supply ducts)	$0.27 \cdot (1 - F_{out}) \cdot CFA_{ServedByAirDistribution}$
DuctSurfaceArea (primary return ducts)	$b_r \cdot F_{out} \cdot CFA_{ServedByAirDistribution}$
DuctSurfaceArea (secondary return ducts)	$b_r \cdot (1 - F_{out}) \cdot CFA_{ServedByAirDistribution}$

where F_{out} is 1.0 for 1-story homes and 0.75 for 2+ story homes and b_r is 0.05 * `NumberofReturnRegisters` with a maximum value of 0.25.

Hydronic Distribution

`HydronicDistribution` systems are defined by:

- `HydronicDistributionType`: "radiator" or "baseboard" or "radiant floor" or "radiant ceiling"

Hydronic And Air Distribution

`HydronicAndAirDistribution` systems are defined by:

- `HydronicAndAirDistributionType`: "fan coil" or "water loop heat pump"

as well as all of the elements described above for an `AirDistribution` system.

Distribution System Efficiency

`DSE` systems are defined by a `AnnualHeatingDistributionSystemEfficiency` and `AnnualCoolingDistributionSystemEfficiency` elements.

> **Warning:** Specifying a DSE for the HVAC distribution system is reflected in the SimulationOutputReport reporting measure outputs, but is not reflected in the raw EnergyPlus simulation outputs.

3.8.6 HPXML Mechanical Ventilation

This section describes elements specified in HPXML's `Systems/MechanicalVentilation`. `Systems/MechanicalVentilation/VentilationFans/VentilationFan` elements can be used to specify whole home ventilation, local ventilation, and/or cooling load reduction.

Whole Home Ventilation

Mechanical ventilation systems that provide whole home ventilation may each be specified as a `Systems/MechanicalVentilation/VentilationFans/VentilationFan` with `UsedForWholeBuildingVentilation='true'`. Inputs including `FanType` and `HoursInOperation` must be provided.

Depending on the type of mechanical ventilation specified, additional elements are required:

FanType	SensibleRecoveryEfficiency	TotalRecoveryEfficiency	AttachedToHVACDistributionSystem
energy recovery ventilator	required	required	
heat recovery ventilator	required		
exhaust only			
supply only			
balanced			
central fan integrated supply (CFIS)			required

Note that `AdjustedSensibleRecoveryEfficiency` and `AdjustedTotalRecoveryEfficiency` can be provided instead of `SensibleRecoveryEfficiency` and `TotalRecoveryEfficiency`.

The ventilation system may be optionally described as a shared system (i.e., serving multiple dwelling units) using `IsSharedSystem`. If not provided, it is assumed to be false.

If the ventilation system is not shared, the following inputs are available:

- `TestedFlowRate` or `RatedFlowRate`: The airflow rate. For a CFIS system, the flow rate should equal the amount of outdoor air provided to the distribution system.
- `FanPower`: The fan power for the highest airflow setting.

If the ventilation system is shared, the following inputs are available:

- `TestedFlowRate` or `RatedFlowRate`: The airflow rate of the entire system.
- `FanPower`: The fan power for the entire system at highest airflow setting.
- `FractionRecirculation`: 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.
- `extension/InUnitFlowRate`: The flow rate delivered to the dwelling unit.
- `extension/PreHeating`: Optional. Element to specify if the supply air is preconditioned by heating equipment. It is not allowed for exhaust only systems. If provided, there are additional child elements required:
  - `Fuel`: Fuel type of the preconditioning heating equipment.
  - `AnnualHeatingEfficiency[Units="COP"]/Value`: Efficiency of the preconditioning heating equipment.
  - `FractionVentilationHeatLoadServed`: Fraction of heating load introduced by the shared ventilation system that is met by the preconditioning heating equipment.
- `extension/PreCooling`: Optional. Element to specify if the supply air is preconditioned by cooling equipment. It is not allowed for exhaust only systems. If provided, there are additional child elements required:
  - `Fuel`: Fuel type of the preconditioning cooling equipment.
  - `AnnualCoolingEfficiency[Units="COP"]/Value`: Efficiency of the preconditioning cooling equipment.
  - `FractionVentilationCoolLoadServed`: Fraction of cooling load introduced by the shared ventilation system that is met by the preconditioning cooling equipment.

Local Ventilation

Kitchen range fans that provide local ventilation may each be specified as a `Systems/MechanicalVentilation/VentilationFans/VentilationFan` with `FanLocation='kitchen'` and `UsedForLocalVentilation='true'`.

Additional fields may be provided per the table below. If not provided, default values will be assumed based on the Building America House Simulation Protocols.

Element Name	Default Value
Quantity [#]	1
RatedFlowRate [cfm]	100
HoursInOperation [hrs/day]	1
FanPower [W]	0.3 * RatedFlowRate
extension/StartHour [0-23]	18

Bathroom fans that provide local ventilation may each be specified as a `Systems/MechanicalVentilation/VentilationFans/VentilationFan` with `FanLocation='bath'` and `UsedForLocalVentilation='true'`.

Additional fields may be provided per the table below. If not provided, default values will be assumed based on the Building America House Simulation Protocols.

Element Name	Default Value
Quantity [#]	NumberofBathrooms
RatedFlowRate [cfm]	50
HoursInOperation [hrs/day]	1
FanPower [W]	0.3 * RatedFlowRate
extension/StartHour [0-23]	7

Cooling Load Reduction

Whole house fans that provide cooling load reduction may each be specified as a `Systems/MechanicalVentilation/VentilationFans/VentilationFan` with `UsedForSeasonalCoolingLoadReduction='true'`. Required elements include `RatedFlowRate` and `FanPower`.

The whole house fan is assumed to operate during hours of favorable outdoor conditions and will take priority over operable windows (natural ventilation).

3.8.7 HPXML Water Heating Systems

Each water heater should be entered as a `Systems/WaterHeating/WaterHeatingSystem`. Inputs including `WaterHeaterType` and `FractionDHWLoadServed` must be provided.

> **Warning:** `FractionDHWLoadServed` represents only the fraction of the hot water load associated with the hot water **fixtures**. Additional hot water load from the clothes washer/dishwasher will be automatically assigned to the appropriate water heater(s).

Depending on the type of water heater specified, additional elements are required/available:

WaterHeaterType	UniformEnergyFactor or EnergyFactor	FirstHourRating	FuelType	TankVolume	HeatingCapacity	RecoveryEfficiency	PerformanceAdjustment	UsesDesuperheater	WaterHeaterInsulation/Jacket/JacketRValue	RelatedHVACSystem
storage water heater	required	required if UEF	<any>	(optional)	(optional)	(optional)		(optional)	(optional)	required if uses desuperheater
instantaneous water heater	required		<any>				(optional)	(optional)		required if uses desuperheater
heat pump water heater	required	required if UEF	electricity	required				(optional)	(optional)	required if uses desuperheater
space-heating boiler with storage tank				required					(optional)	required
space-heating boiler with tankless coil										required

For storage water heaters, the tank volume in gallons, heating capacity in Btuh, and recovery efficiency can be optionally provided. If not provided, default values for the tank volume and heating capacity will be assumed based on Table 8 in the 2014 Building America House Simulation Protocols and a default recovery efficiency shown in the table below will be assumed based on regression analysis of AHRI certified water heaters.

EnergyFactor	RecoveryEfficiency (default)
>= 0.75	0.778114 * EF + 0.276679
< 0.75	0.252117 * EF + 0.607997

For tankless water heaters, a performance adjustment due to cycling inefficiencies can be provided. If not provided, a default value of 0.94 will apply if Uniform Energy Factor (UEF) is provided or 0.92 will apply if Energy Factor (EF) is provided.

For combi boiler systems, the `RelatedHVACSystem` must point to a `HeatingSystem` of type "Boiler". For combi boiler systems with a storage tank, the storage tank losses (deg-F/hr) can be entered as `StandbyLoss`; if not provided, a default value based on the AHRI Directory of Certified Product Performance will be calculated.

For water heaters that are connected to a desuperheater, the `RelatedHVACSystem` must either point to a `HeatPump` or a `CoolingSystem`.

The water heater `Location` can be optionally entered as one of the following:

Location	Description	Temperature	Building Type
living space	Above-grade conditioned floor area	EnergyPlus calculation	Any
basement - conditioned	Below-grade conditioned floor area	EnergyPlus calculation	Any
basement - unconditioned		EnergyPlus calculation	Any
attic - unvented		EnergyPlus calculation	Any
attic - vented		EnergyPlus calculation	Any
garage	Single-family garage (not shared parking garage)	EnergyPlus calculation	Any
crawlspace - unvented		EnergyPlus calculation	Any
crawlspace - vented		EnergyPlus calculation	Any
other exterior	Outside	EnergyPlus calculation	Any
other housing unit	E.g., conditioned adjacent unit or corridor	Same as conditioned space	Attached/Multifamily only
other heated space	E.g., shared laundry/equipment space	Average of conditioned space and outside; minimum of 68F	Attached/Multifamily only
other multifamily buffer space	E.g., enclosed unconditioned stairwell	Average of conditioned space and outside; minimum of 50F	Attached/Multifamily only
other non-freezing space	E.g., shared parking garage ceiling	Floats with outside; minimum of 40F	Attached/Multifamily only

If the location is not provided, a default water heater location will be assumed based on IECC climate zone:

IECC Climate Zone	Location (default)
1-3, excluding 3A	garage if present, otherwise living space
3A, 4-8, unknown	conditioned basement if present, otherwise unconditioned basement if present, otherwise living space

The setpoint temperature may be provided as `HotWaterTemperature`; if not provided, 125F is assumed.

The water heater may be optionally described as a shared system (i.e., serving multiple dwelling units or a shared laundry room) using `IsSharedSystem`. If not provided, it is assumed to be false. If provided and true, `NumberofUnitsServed` must also be specified, where the value is the number of dwelling units served either indirectly (e.g., via shared laundry room) or directly.

3.8.8 HPXML Hot Water Distribution

A single `Systems/WaterHeating/HotWaterDistribution` must be provided if any water heating systems are specified. Inputs including `SystemType` and `PipeInsulation/PipeRValue` must be provided. Note: Any hot water distribution associated with a shared laundry room in attached/multifamily buildings should not be defined.

Standard

For a `SystemType/Standard` (non-recirculating) system within the dwelling unit, the following element are used:

- `PipingLength`: Optional. Measured length of hot water piping from the hot water heater (or from a shared recirculation loop serving multiple dwelling units) to the farthest hot water fixture, measured longitudinally from plans, assuming the hot water piping does not run diagonally, plus 10 feet of piping for each floor level, plus 5 feet of piping for unconditioned basements (if any) If not provided, a default `PipingLength` will be calculated using the following equation from ANSI/RESNET/ICC 301-2019.

$$PipeL = 2.0 \cdot (\frac{CFA}{NCfl})^{0.5} + 10.0 \cdot NCfl + 5.0 \cdot bsmnt$$

Where, PipeL = piping length [ft], CFA = conditioned floor area [ft^2], NCfl = number of conditioned floor levels number of conditioned floor levels in the residence including conditioned basements, bsmnt = presence = 1.0 or absence = 0.0 of an unconditioned basement in the residence.

Recirculation

For a `SystemType/Recirculation` system within the dwelling unit, the following elements are used:

- `ControlType`: One of "manual demand control", "presence sensor demand control", "temperature", "timer", or "no control".
- `RecirculationPipingLoopLength`: Optional. If not provided, the default value will be calculated by using the equation shown in the table below. Measured recirculation loop length including both supply and return sides, measured longitudinally from plans, assuming the hot water piping does not run diagonally, plus 20 feet of piping for each floor level greater than one plus 10 feet of piping for unconditioned basements.
- `BranchPipingLoopLength`: Optional. If not provided, the default value will be assumed as shown in the table below. Measured length of the branch hot water piping from the recirculation loop to the farthest hot water fixture from the recirculation loop, measured longitudinally from plans, assuming the branch hot water piping does not run diagonally.
- `PumpPower`: Optional. If not provided, the default value will be assumed as shown in the table below. Pump Power in Watts.

Element Name	Default Value
RecirculationPipingLoopLength [ft]	$2.0 \cdot (2.0 \cdot (\frac{CFA}{NCfl})^{0.5} + 10.0 \cdot NCfl + 5.0 \cdot bsmnt) - 20.0$
BranchPipingLoopLength [ft]	10
Pump Power [W]	50

Shared Recirculation

In addition to the hot water distribution systems within the dwelling unit, the pump energy use of a shared recirculation system in an Attached/Multifamily building can also be described using the following elements:

- *extension/SharedRecirculation/NumberofUnitsServed*: Number of dwelling units served by the shared pump.
- *extension/SharedRecirculation/PumpPower*: Optional. If not provided, the default value will be assumed as shown in the table below. Shared pump power in Watts.
- *extension/SharedRecirculation/ControlType*: One of "manual demand control", "presence sensor demand control", "timer", or "no control".

Element Name	Default Value
Pump Power [W]	220 (0.25 HP pump w/ 85% motor efficiency)

Note that when defining a shared recirculation system, the hot water distribution system type within the dwelling unit must be standard (`SystemType/Standard`). This is because a stacked recirculation system (i.e., shared recirculation loop plus an additional recirculation system within the dwelling unit) is more likely to indicate input errors than reflect an actual real-world scenario.

Drain Water Heat Recovery

In addition, a `HotWaterDistribution/DrainWaterHeatRecovery` (DWHR) may be specified. The DWHR system is defined by:

- `FacilitiesConnected`: 'one' if there are multiple showers and only one of them is connected to a DWHR; 'all' if there is one shower and it's connected to a DWHR or there are two or more showers connected to a DWHR
- `EqualFlow`: 'true' if the DWHR supplies pre-heated water to both the fixture cold water piping and the hot water heater potable supply piping
- `Efficiency`: As rated and labeled in accordance with CSA 55.1

3.8.9 HPXML Water Fixtures

Water fixtures should be entered as `Systems/WaterHeating/WaterFixture` elements. Each fixture must have `WaterFixtureType` and `LowFlow` elements provided. Fixtures should be specified as low flow if they are <= 2.0 gpm.

A `WaterHeating/extension/WaterFixturesUsageMultiplier` can also be optionally provided that scales hot water usage; if not provided, it is assumed to be 1.0.

3.8.10 HPXML Solar Thermal

A solar hot water system can be entered as a `Systems/SolarThermal/SolarThermalSystem`. The `SystemType` element must be 'hot water'.

Solar hot water systems can be described with either simple or detailed inputs.

Simple Model

If using simple inputs, the following elements are used:

- `SolarFraction`: Portion of total conventional hot water heating load (delivered energy and tank standby losses). Can be obtained from Directory of SRCC OG-300 Solar Water Heating System Ratings or NREL's System Advisor Model or equivalent.
- `ConnectedTo`: Optional. If not specified, applies to all water heaters in the building. If specified, must point to a `WaterHeatingSystem`.

Detailed Model

If using detailed inputs, the following elements are used:

- `CollectorArea`: in units of ft^2
- `CollectorLoopType`: 'liquid indirect' or 'liquid direct' or 'passive thermosyphon'
- `CollectorType`: 'single glazing black' or 'double glazing black' or 'evacuated tube' or 'integrated collector storage'

- `CollectorAzimuth`
- `CollectorTilt`
- `CollectorRatedOpticalEfficiency`: FRTA (y-intercept); see Directory of SRCC OG-100 Certified Solar Collector Ratings
- `CollectorRatedThermalLosses`: FRUL (slope, in units of Btu/hr-ft^2-R); see Directory of SRCC OG-100 Certified Solar Collector Ratings
- `StorageVolume`: Optional. If not provided, the default value in gallons will be calculated as 1.5 * CollectorArea
- `ConnectedTo`: Must point to a `WaterHeatingSystem`. The connected water heater cannot be of type space-heating boiler or attached to a desuperheater.

3.8.11 HPXML Photovoltaics

Each solar electric (photovoltaic) system should be entered as a `Systems/Photovoltaics/PVSystem`. The following elements, some adopted from the PVWatts model, are required for each PV system:

- `Location`: 'ground' or 'roof' mounted
- `ModuleType`: 'standard', 'premium', or 'thin film'
- `Tracking`: 'fixed' or '1-axis' or '1-axis backtracked' or '2-axis'
- `ArrayAzimuth`
- `ArrayTilt`
- `MaxPowerOutput`

Inputs including `InverterEfficiency`, `SystemLossesFraction`, and `YearModulesManufactured` can be optionally entered. If `InverterEfficiency` is not provided, the default value of 0.96 is assumed.

`SystemLossesFraction` includes the effects of soiling, shading, snow, mismatch, wiring, degradation, etc. If neither `SystemLossesFraction` or `YearModulesManufactured` are provided, a default value of 0.14 will be used. If `SystemLossesFraction` is not provided but `YearModulesManufactured` is provided, `SystemLossesFraction` will be calculated using the following equation.

$$SystemLossesFraction = 1.0 - (1.0 - 0.14) \cdot (1.0 - (1.0 - 0.995^{(CurrentYear - YearModulesManufactured)}))$$

The PV system may be optionally described as a shared system (i.e., serving multiple dwelling units) using `IsSharedSystem`. If not provided, it is assumed to be false. If provided and true, the total number of bedrooms across all dwelling units served by the system must be entered as `extension/NumberofBedroomsServed`. PV generation will be apportioned to the dwelling unit using its number of bedrooms divided by the total number of bedrooms in the building.

3.9 HPXML Appliances

This section describes elements specified in HPXML's `Appliances`.

The `Location` for each appliance can be optionally provided as one of the following:

Location	Description	Building Type
living space	Above-grade conditioned floor area	Any
basement - conditioned	Below-grade conditioned floor area	Any
basement - unconditioned		Any
garage	Single-family garage (not shared parking garage)	Any
other housing unit	E.g., conditioned adjacent unit or corridor	Attached/Multifamily only
other heated space	E.g., shared laundry/equipment space	Attached/Multifamily only
other multifamily buffer space	E.g., enclosed unconditioned stairwell	Attached/Multifamily only
other non-freezing space	E.g., shared parking garage ceiling	Attached/Multifamily only

If the location is not specified, the appliance is assumed to be in the living space.

3.9.1 HPXML Clothes Washer

A single `Appliances/ClothesWasher` element can be specified; if not provided, a clothes washer will not be modeled.

Several EnergyGuide label inputs describing the efficiency of the appliance can be provided. If the complete set of efficiency inputs is not provided, the following default values representing a standard clothes washer from 2006 will be used.

Element Name	Default Value
IntegratedModifiedEnergyFactor [ft^3/kWh-cyc]	1.0
RatedAnnualkWh [kWh/yr]	400
LabelElectricRate [$/kWh]	0.12
LabelGasRate [$/therm]	1.09
LabelAnnualGasCost [$]	27.0
Capacity [ft^3]	3.0
LabelUsage [cyc/week]	6

If `ModifiedEnergyFactor` is provided instead of `IntegratedModifiedEnergyFactor`, it will be converted using the following equation based on the Interpretation on ANSI/RESNET 301-2014 Clothes Washer IMEF.

$$IntegratedModifiedEnergyFactor = \frac{ModifiedEnergyFactor - 0.503}{0.95}$$

An `extension/UsageMultiplier` can also be optionally provided that scales energy and hot water usage; if not provided, it is assumed to be 1.0.

The clothes washer may be optionally described as a shared appliance (i.e., in a shared laundry room) using `IsSharedAppliance`. If not provided, it is assumed to be false. If provided and true, `AttachedToWaterHeatingSystem` must also be specified and must reference a shared water heater.

3.9.2 HPXML Clothes Dryer

A single `Appliances/ClothesDryer` element can be specified; if not provided, a clothes dryer will not be modeled. The dryer's `FuelType` must be provided.

Several EnergyGuide label inputs describing the efficiency of the appliance can be provided. If the complete set of efficiency inputs is not provided, the following default values representing a standard clothes dryer from 2006 will be used.

Element Name	Default Value
CombinedEnergyFactor [lb/kWh]	3.01
ControlType	timer

If `EnergyFactor` is provided instead of `CombinedEnergyFactor`, it will be converted into `CombinedEnergyFactor` using the following equation based on the Interpretation on ANSI/RESNET/ICC 301-2014 Clothes Dryer CEF.

$$CombinedEnergyFactor = \frac{EnergyFactor}{1.15}$$

An `extension/UsageMultiplier` can also be optionally provided that scales energy usage; if not provided, it is assumed to be 1.0.

An optional `extension/IsVented` element can be used to indicate whether the clothes dryer is vented. If not provided, it is assumed that the clothes dryer is vented. If the clothes dryer is vented, an optional `extension/VentedFlowRate` element can be used to specify the exhaust cfm. If not provided, it is assumed that the clothes dryer vented flow rate is 100 cfm.

The clothes dryer may be optionally described as a shared appliance (i.e., in a shared laundry room) using `IsSharedAppliance`. If not provided, it is assumed to be false.

3.9.3 HPXML Dishwasher

A single `Appliances/Dishwasher` element can be specified; if not provided, a dishwasher will not be modeled.

Several EnergyGuide label inputs describing the efficiency of the appliance can be provided. If the complete set of efficiency inputs is not provided, the following default values representing a standard dishwasher from 2006 will be used.

Element Name	Default Value
RatedAnnualkWh [kwh/yr]	467
LabelElectricRate [$/kWh]	0.12
LabelGasRate [$/therm]	1.09
LabelAnnualGasCost [$]	33.12
PlaceSettingCapacity [#]	12
LabelUsage [cyc/week]	4

If `EnergyFactor` is provided instead of `RatedAnnualkWh`, it will be converted into `RatedAnnualkWh` using the following equation based on ANSI/RESNET/ICC 301-2014.

$$RatedAnnualkWh = \frac{215.0}{EnergyFactor}$$

An `extension/UsageMultiplier` can also be optionally provided that scales energy and hot water usage; if not provided, it is assumed to be 1.0.

The dishwasher may be optionally described as a shared appliance (i.e., in a shared laundry room) using `IsSharedAppliance`. If not provided, it is assumed to be false. If provided and true, `AttachedToWaterHeatingSystem` must also be specified and must reference a shared water heater.

3.9.4 HPXML Refrigerators

Multiple `Appliances/Refrigerator` elements can be specified; if none are provided, refrigerators will not be modeled.

The efficiency of the refrigerator can be optionally entered as `RatedAnnualkWh` or `extension/AdjustedAnnualkWh`. If neither are provided, `RatedAnnualkWh` will be defaulted to represent a standard refrigerator from 2006 using the following equation based on ANSI/RESNET/ICC 301-2019.

$$RatedAnnualkWh = 637.0 + 18.0 \cdot NumberofBedrooms$$

Optional `extension/WeekdayScheduleFractions`, `extension/WeekendScheduleFractions`, and `extension/MonthlyScheduleMultipliers` can be provided; if not provided, values from Figures 16 & 24 of the Building America House Simulation Protocols are used. An `extension/UsageMultiplier` can also be optionally provided that scales energy usage; if not provided, it is assumed to be 1.0.

If multiple refrigerators are specified, there must be exactly one refrigerator described with `PrimaryIndicator='true'`.

The `Location` of a primary refrigerator is described in the Appliances section. If `Location` is not provided for a non-primary refrigerator, its location will be chosen based on the presence of spaces and the "Default Priority" indicated below.

Location	Default Priority
garage	1
basement - unconditioned	2
basement - conditioned	3
living space	4

3.9.5 HPXML Freezers

Multiple `Appliances/Freezer` elements can be provided; if none provided, standalone freezers will not be modeled.

The efficiency of the freezer can be optionally entered as RatedAnnualkWh or extension/AdjustedAnnualkWh. If neither are provided, RatedAnnualkWh will be defaulted to represent a benchmark freezer according to the Building America House Simulation Protocols (319.8 kWh/year).

Optional `extension/WeekdayScheduleFractions`, `extension/WeekendScheduleFractions`, and `extension/MonthlyScheduleMultipliers` can be provided; if not provided, values from Figures 16 & 24 of the Building America House Simulation Protocols are used. An extension/UsageMultiplier can also be optionally provided that scales energy usage; if not provided, it is assumed to be 1.0.

3.9.6 HPXML Cooking Range/Oven

A single pair of `Appliances/CookingRange` and `Appliances/Oven` elements can be specified; if not provided, a range/oven will not be modeled. The `FuelType` of the range must be provided.

Inputs including `CookingRange/IsInduction` and `Oven/IsConvection` can be optionally provided. The following default values will be assumed unless a complete set of the optional variables is provided.

Element Name	Default Value
IsInduction	false
IsConvection	false

Optional `CookingRange/extension/WeekdayScheduleFractions`, `CookingRange/extension/WeekendScheduleFractions`, and `CookingRange/extension/MonthlyScheduleMultipliers` can be provided; if not provided, values from Figures 22 & 24 of the Building America House Simulation Protocols are used. An `CookingRange/extension/UsageMultiplier` can also be optionally provided that scales energy usage; if not provided, it is assumed to be 1.0.

3.9.7 HPXML Dehumidifier

A single Appliance/Dehumidifier element can be specified; if not provided, a dehumidifier will not be modeled. The Capacity (pints/day), DehumidistatSetpoint (relative humidity as a fraction, 0-1), and FractionDehumidificationLoadServed (0-1) must be provided. The efficiency of the dehumidifier can either be entered as an IntegratedEnergyFactor or EnergyFactor.

3.10 HPXML Lighting

This section describes elements specified in HPXML's Lighting.

3.10.1 HPXML Lighting Groups

The building's lighting is described by nine LightingGroup elements, each of which is the combination of:

- LightingType: 'LightEmittingDiode', 'CompactFluorescent', and 'FluorescentTube'
- Location: 'interior', 'garage', and 'exterior'

The fraction of lamps of the given type in the given location are provided as the LightingGroup/FractionofUnitsInLocation. The fractions for a given location cannot sum to greater than 1. If the fractions sum to less than 1, the remainder is assumed to be incandescent lighting. Garage lighting values are ignored if the building has no garage.

Optional extension/InteriorUsageMultiplier, extension/ExteriorUsageMultiplier, and extension/GarageUsageMultiplier can be provided that scales energy usage; if not provided, they are assumed to be 1.0.

An optional extension/ExteriorHolidayLighting can also be provided to define additional exterior holiday lighting; if not provided, none will be modeled. If provided, child elements Load[Units='kWh/day']/Value, PeriodBeginMonth/PeriodBeginDayOfMonth, PeriodEndMonth/PeriodEndDayOfMonth, WeekdayScheduleFractions, and WeekendScheduleFractions can be optionally provided. For the child elements not provided, the following default values will be used.

Element Name	Default Value
Load[Units='kWh/day']/Value	1.1 for single-family detached and 0.55 for others
PeriodBeginMonth/PeriodBeginDayOfMonth	11/24 (November 24)
PeriodEndMonth/PeriodEndDayOfMonth	1/6 (January 6)
WeekdayScheduleFractions	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.008, 0.098, 0.168, 0.194, 0.284, 0.192, 0.037, 0.019
WeekendScheduleFractions	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.008, 0.098, 0.168, 0.194, 0.284, 0.192, 0.037, 0.019

Finally, optional schedules can be defined:

- **Interior**: Optional extension/InteriorWeekdayScheduleFractions, extension/InteriorWeekendScheduleFractions, and extension/InteriorMonthlyScheduleMultipliers can be provided; if not provided, values will be calculated using Lighting Calculation Option 2 (location-dependent lighting profile) of the Building America House Simulation Protocols.

- **Garage**: Optional `extension/GarageWeekdayScheduleFractions`, `extension/GarageWeekendScheduleFractions`, and `extension/GarageMonthlyScheduleMultipliers` can be provided; if not provided, values from Appendix C Table 8 of the Title 24 2016 Residential Alternative Calculation Method Reference Manual are used.
- **Exterior**: Optional `extension/ExteriorWeekdayScheduleFractions`, `extension/ExteriorWeekendScheduleFractions`, and `extension/ExteriorMonthlyScheduleMultipliers` can be provided; if not provided, values from Appendix C Table 8 of the Title 24 2016 Residential Alternative Calculation Method Reference Manual are used.

3.10.2 HPXML Ceiling Fans

Each ceiling fan (or set of identical ceiling fans) should be entered as a `CeilingFan`. The `Airflow/Efficiency` (at medium speed) and `Quantity` can be provided, otherwise the following default assumptions are used from ANSI/RESNET/ICC 301-2019.

Element Name	Default Value
Airflow/Efficiency [cfm/W]	3000/42.6
Quantity [#]	NumberofBedrooms+1

In addition, a reduced cooling setpoint can be specified for summer months when ceiling fans are operating. See the Thermostat section for more information.

3.11 HPXML Pool

A `Pools/Pool` element can be specified; if not provided, a pool will not be modeled.

A `PoolPumps/PoolPump` element is required. The annual energy consumption of the pool pump (`Load[Units='kWh/year']/Value`) can be provided, otherwise they will be calculated using the following equation based on the Building America House Simulation Protocols.

$$PoolPumpkWhs = 158.5/0.070 \cdot (0.5 + 0.25 \cdot NumberofBedrooms/3 + 0.35 \cdot ConditionedFloorArea/1920)$$

A `Heater` element can be specified; if not provided, a pool heater will not be modeled. Currently only pool heaters specified with `Heater[Type='gas fired' or Type='electric resistance' or Type='heat pump']` are recognized. The annual energy consumption (`Load[Units='kWh/year' or Units='therm/year']/Value`) can be provided, otherwise they will be calculated using the following equations from the Building America House Simulation Protocols.

$$GasFiredTherms = 3.0/0.014 \cdot (0.5 + 0.25 \cdot NumberofBedrooms/3 + 0.35 \cdot ConditionedFloorArea/1920)$$

$$ElectricResistancekWhs = 8.3/0.004 \cdot (0.5 + 0.25 \cdot NumberofBedrooms/3 + 0.35 \cdot ConditionedFloorArea/1920)$$

$$HeatPumpkWhs = ElectricResistancekWhs/5.0$$

A `PoolPump/extension/UsageMultiplier` can also be optionally provided that scales pool pump energy usage; if not provided, it is assumed to be 1.0. A `Heater/extension/UsageMultiplier` can also be optionally provided that scales pool heater energy usage; if not provided, it is assumed to be 1.0. Optional `extension/WeekdayScheduleFractions`, `extension/WeekendScheduleFractions`, and `extension/MonthlyScheduleMultipliers` can be provided for `HotTubPump` and `Heater`; if not provided, values from Figures 23 & 24 of the Building America House Simulation Protocols are used.

3.12 HPXML Hot Tub

A `HotTubs/HotTub` element can be specified; if not provided, a hot tub will not be modeled.

A `HotTubPumps/HotTubPump` element is required. The annual energy consumption of the hot tub pump (`Load[Units='kWh/year']/Value`) can be provided, otherwise they will be calculated using the following equation based on the Building America House Simulation Protocols.

$$HotTubPumpkWhs = 59.5/0.059 \cdot (0.5 + 0.25 \cdot NumberofBedrooms/3 + 0.35 \cdot ConditionedFloorArea/1920)$$

A `Heater` element can be specified; if not provided, a hot tub heater will not be modeled. Currently only hot tub heaters specified with `Heater[Type='gas fired' or Type='electric resistance' or Type='heat pump']` are recognized. The annual energy consumption (`Load[Units='kWh/year' or Units='therm/year']/Value`) can be provided, otherwise they will be calculated using the following equations from the Building America House Simulation Protocols.

$$GasFiredTherms = 0.87/0.011 \cdot (0.5 + 0.25 \cdot NumberofBedrooms/3 + 0.35 \cdot ConditionedFloorArea/1920)$$

$$ElectricResistancekWhs = 49.0/0.048 \cdot (0.5 + 0.25 \cdot NumberofBedrooms/3 + 0.35 \cdot ConditionedFloorArea/1920)$$

$$HeatPumpkWhs = ElectricResistancekWhs/5.0$$

A `HotTubPump/extension/UsageMultiplier` can also be optionally provided that scales hot tub pump energy usage; if not provided, it is assumed to be 1.0. A `Heater/extension/UsageMultiplier` can also be optionally provided that scales hot tub heater energy usage; if not provided, it is assumed to be 1.0. Optional `extension/WeekdayScheduleFractions`, `extension/WeekendScheduleFractions`, and `extension/MonthlyScheduleMultipliers` can be provided for `PoolPump` and `Heater`; if not provided, values from Figures 23 & 24 of the Building America House Simulation Protocols are used.

3.13 HPXML Misc Loads

This section describes elements specified in HPXML's `MiscLoads`.

3.13.1 HPXML Plug Loads

Misc electric plug loads can be provided by entering `PlugLoad` elements. Currently only plug loads specified with `PlugLoadType='other'`, `PlugLoadType='TV other'`, `PlugLoadType='electric vehicle charging'`, or `PlugLoadType='well pump'` are recognized. The 'other' and 'TV other' plug loads are required to represent the typical home; the other less common plug loads will only be modeled if provided.

The annual energy consumption (`Load[Units='kWh/year']/Value`), `Location`, `extension/FracSensible`, and `extension/FracLatent` elements are optional. If not provided, they will be defaulted as follows. Annual energy consumption equations are based on ANSI/RESNET/ICC 301-2019 or the Building America House Simulation Protocols.

Plug Load Type	kWh/year	Location	FracSensible	FracLatent
other	0.91*CFA	interior	0.855	0.045
TV other	413.0 + 69.0*NBr	interior	1.0	0.0
electric vehicle charging	1666.67	exterior	0.0	0.0
well pump	50.8/0.127*(0.5 + 0.25*NBr/3 + 0.35*CFA/1920)	exterior	0.0	0.0

where CFA is the conditioned floor area and NBr is the number of bedrooms.

The electric vehicle charging default kWh/year is calculated using:

$$VehiclekWhs = AnnualMiles * kWhPerMile/(EVChargerEfficiency * EVBatteryEfficiency)$$

where AnnualMiles=4500, kWhPerMile=0.3, EVChargerEfficiency=0.9, and EVBatteryEfficiency=0.9.

An `extension/UsageMultiplier` can also be optionally provided that scales energy usage; if not provided, it is assumed to be 1.0. Optional `extension/WeekdayScheduleFractions`, `extension/WeekendScheduleFractions`, and `extension/MonthlyScheduleMultipliers` can be provided. If not provided, values from Figures 23 & 24 of the Building America House Simulation Protocols are used for `PlugLoadType='other'`, `PlugLoadType='electric vehicle charging'`, and `PlugLoadType='well pump'`; values from the American Time Use Survey are used for `PlugLoadType='TV other'`.

3.13.2 HPXML Fuel Loads

Misc fuel loads can be provided by entering `FuelLoad` elements. Currently only fuel loads specified with `FuelLoadType='grill'`, `FuelLoadType='lighting'`, or `FuelLoadType='fireplace'` are recognized. These less common fuel loads will only be modeled if provided.

The annual energy consumption (`Load[Units='therm/year']/Value`), `Location`, `extension/FracSensible`, and `extension/FracLatent` elements are also optional. If not provided, they will be defaulted as follows. Annual energy consumption equations are based on the Building America House Simulation Protocols.

Plug Load Type	therm/year	Location	FracSensible	FracLatent
grill	0.87/0.029*(0.5 + 0.25*NBr/3 + 0.35*CFA/1920)	exterior	0.0	0.0
lighting	0.22/0.012*(0.5 + 0.25*NBr/3 + 0.35*CFA/1920)	exterior	0.0	0.0
fireplace	1.95/0.032*(0.5 + 0.25*NBr/3 + 0.35*CFA/1920)	interior	0.5	0.1

where CFA is the conditioned floor area and NBr is the number of bedrooms.

An `extension/UsageMultiplier` can also be optionally provided that scales energy usage; if not provided, it is assumed to be 1.0. Optional `extension/WeekdayScheduleFractions`, `extension/WeekendScheduleFractions`, and `extension/MonthlyScheduleMultipliers` can be provided; if not provided, values from Figures 23 & 24 of the Building America House Simulation Protocols are used.

3.14 Validating & Debugging Errors

When running HPXML files, errors may occur because:

1. An HPXML file provided is invalid (either relative to the HPXML schema or the EnergyPlus Use Case).
2. An unexpected EnergyPlus simulation error occurred.

If an error occurs, first look in the run.log for details. If there are no errors in that log file, then the error may be in the EnergyPlus simulation – see eplusout.err.

Contact us if you can't figure out the cause of an error.

3.15 Sample Files

Dozens of sample HPXML files are included in the workflow/sample_files directory. The sample files help to illustrate how different building components are described in HPXML.

Each sample file generally makes one isolated change relative to the base HPXML (base.xml) building. For example, the base-dhw-dwhr.xml file adds a `DrainWaterHeatRecovery` element to the building.

You may find it useful to search through the files for certain HPXML elements or compare (diff) a sample file to the base.xml file.

CHAPTER 4

SimulationOutputReport Measure

The SimulationOutputReport reporting measure generates a variety of annual (and optionally, timeseries) outputs for a residential HPXML-based model.

4.1 Annual Outputs

The measure will always generate an annual CSV output file called results_annual.csv, co-located with the EnergyPlus output. The CSV file includes the following sections of output:

4.1.1 Annual Energy Consumption by Fuel Type

Current fuel types are:

Type	Notes
Electricity: Total (MBtu)	
Electricity: Net (MBtu)	Excludes any PV generation.
Natural Gas: Total (MBtu)	
Fuel Oil: Total (MBtu)	Includes "fuel oil", "fuel oil 1", "fuel oil 2", "fuel oil 4", "fuel oil 5/6", "kerosene", and "diesel"
Propane: Total (MBtu)	
Wood: Total (MBtu)	
Wood Pellets: Total (MBtu)	
Coal: Total (MBtu)	Includes "coal", "anthracite coal", "bituminous coal", and "coke".

4.1.2 Annual Energy Consumption By Fuel Type and End Use

Current end use/fuel type combinations are:

Type	Notes
Electricity: Heating (MBtu)	
Electricity: Heating Fans/Pumps (MBtu)	
Electricity: Cooling (MBtu)	
Electricity: Cooling Fans/Pumps (MBtu)	
Electricity: Hot Water (MBtu)	
Electricity: Hot Water Recirc Pump (MBtu)	
Electricity: Hot Water Solar Thermal Pump (MBtu)	
Electricity: Lighting Interior (MBtu)	
Electricity: Lighting Garage (MBtu)	
Electricity: Lighting Exterior (MBtu)	
Electricity: Mech Vent (MBtu)	
Electricity: Mech Vent Preheating (MBtu)	
Electricity: Mech Vent Precooling (MBtu)	
Electricity: Whole House Fan (MBtu)	
Electricity: Refrigerator (MBtu)	
Electricity: Freezer (MBtu)	
Electricity: Dehumidifier (MBtu)	
Electricity: Dishwasher (MBtu)	
Electricity: Clothes Washer (MBtu)	
Electricity: Clothes Dryer (MBtu)	
Electricity: Range/Oven (MBtu)	
Electricity: Ceiling Fan (MBtu)	
Electricity: Television (MBtu)	
Electricity: Plug Loads (MBtu)	
Electricity: Electric Vehicle Charging (MBtu)	
Electricity: Well Pump (MBtu)	
Electricity: Pool Heater (MBtu)	
Electricity: Pool Pump (MBtu)	
Electricity: Hot Tub Heater (MBtu)	
Electricity: Hot Tub Pump (MBtu)	
Electricity: PV (MBtu)	
Natural Gas: Heating (MBtu)	
Natural Gas: Hot Water (MBtu)	
Natural Gas: Clothes Dryer (MBtu)	
Natural Gas: Range/Oven (MBtu)	
Natural Gas: Mech Vent Preheating (MBtu)	
Natural Gas: Mech Vent Precooling (MBtu)	
Natural Gas: Pool Heater (MBtu)	
Natural Gas: Hot Tub Heater (MBtu)	
Natural Gas: Grill (MBtu)	
Natural Gas: Lighting (MBtu)	
Natural Gas: Fireplace (MBtu)	
Fuel Oil: Heating (MBtu)	
Fuel Oil: Hot Water (MBtu)	
Fuel Oil: Clothes Dryer (MBtu)	
Fuel Oil: Range/Oven (MBtu)	

Continued on next page

Table 1 – continued from previous page

Type	Notes
Fuel Oil: Mech Vent Preheating (MBtu)	
Fuel Oil: Mech Vent Precooling (MBtu)	
Fuel Oil: Grill (MBtu)	
Fuel Oil: Lighting (MBtu)	
Fuel Oil: Fireplace (MBtu)	
Propane: Heating (MBtu)	
Propane: Hot Water (MBtu)	
Propane: Clothes Dryer (MBtu)	
Propane: Range/Oven (MBtu)	
Propane: Mech Vent Preheating (MBtu)	
Propane: Mech Vent Precooling (MBtu)	
Propane: Grill (MBtu)	
Propane: Lighting (MBtu)	
Propane: Fireplace (MBtu)	
Wood Cord: Heating (MBtu)	
Wood Cord: Hot Water (MBtu)	
Wood Cord: Clothes Dryer (MBtu)	
Wood Cord: Range/Oven (MBtu)	
Wood Cord: Mech Vent Preheating (MBtu)	
Wood Cord: Mech Vent Precooling (MBtu)	
Wood Cord: Grill (MBtu)	
Wood Cord: Lighting (MBtu)	
Wood Cord: Fireplace (MBtu)	
Wood Pellets: Heating (MBtu)	
Wood Pellets: Hot Water (MBtu)	
Wood Pellets: Clothes Dryer (MBtu)	
Wood Pellets: Range/Oven (MBtu)	
Wood Pellets: Mech Vent Preheating (MBtu)	
Wood Pellets: Mech Vent Precooling (MBtu)	
Wood Pellets: Grill (MBtu)	
Wood Pellets: Lighting (MBtu)	
Wood Pellets: Fireplace (MBtu)	
Coal: Heating (MBtu)	
Coal: Hot Water (MBtu)	
Coal: Clothes Dryer (MBtu)	
Coal: Range/Oven (MBtu)	
Coal: Mech Vent Preheating (MBtu)	
Coal: Mech Vent Precooling (MBtu)	
Coal: Grill (MBtu)	
Coal: Lighting (MBtu)	
Coal: Fireplace (MBtu)	

4.1.3 Annual Building Loads

Current annual building loads are:

Type	Notes
Load: Heating (MBtu)	Includes HVAC distribution losses.
Load: Cooling (MBtu)	Includes HVAC distribution losses.
Load: Hot Water: Delivered (MBtu)	Includes contributions by desuperheaters or solar thermal systems.
Load: Hot Water: Tank Losses (MBtu)	
Load: Hot Water: Desuperheater (MBtu)	Load served by the desuperheater.
Load: Hot Water: Solar Thermal (MBtu)	Load served by the solar thermal system.

4.1.4 Annual Unmet Building Loads

Current annual unmet building loads are:

Type	Notes
Unmet Load: Heating (MBtu)	
Unmet Load: Cooling (MBtu)	

These numbers reflect the amount of heating/cooling load that is not met by the HVAC system, indicating the degree to which the HVAC system is undersized. An HVAC system with sufficient capacity to perfectly maintain the thermostat setpoints will report an unmet load of zero.

Note that if a building has partial (or no) HVAC system, the unserved load will not be included in the unmet load outputs. For example, if a building has a room air conditioner that meets 33% of the cooling load, the remaining 67% of the load is not included in the unmet load. Rather, the unmet load is only the amount of load that the room AC *should* be serving but is not.

4.1.5 Peak Building Electricity

Current peak building electricity outputs are:

Type	Notes
Peak Electricity: Winter Total (W)	Winter season defined by operation of the heating system.
Peak Electricity: Summer Total (W)	Summer season defined by operation of the cooling system.

4.1.6 Peak Building Loads

Current peak building loads are:

Type	Notes
Peak Load: Heating (kBtu)	Includes HVAC distribution losses.
Peak Load: Cooling (kBtu)	Includes HVAC distribution losses.

4.1.7 Annual Component Building Loads

Component loads represent the estimated contribution of different building components to the annual heating/cooling building loads. The sum of component loads for heating (or cooling) will roughly equal the annual heating (or cooling) building load reported above. Current component loads disaggregated by Heating/Cooling are:

Type	Notes
Component Load: *: Roofs (MBtu)	Heat gain/loss through HPXML `Roof` elements adjacent to conditioned space
Component Load: *: Ceilings (MBtu)	Heat gain/loss through HPXML `FrameFloor` elements (inferred to be ceilings) adjacent to conditioned space
Component Load: *: Walls (MBtu)	Heat gain/loss through HPXML `Wall` elements adjacent to conditioned space
Component Load: *: Rim Joists (MBtu)	Heat gain/loss through HPXML `RimJoist` elements adjacent to conditioned space
Component Load: *: Foundation Walls (MBtu)	Heat gain/loss through HPXML `FoundationWall` elements adjacent to conditioned space
Component Load: *: Doors (MBtu)	Heat gain/loss through HPXML `Door` elements adjacent to conditioned space
Component Load: *: Windows (MBtu)	Heat gain/loss through HPXML `Window` elements adjacent to conditioned space, including solar
Component Load: *: Skylights (MBtu)	Heat gain/loss through HPXML `Skylight` elements adjacent to conditioned space, including solar
Component Load: *: Floors (MBtu)	Heat gain/loss through HPXML `FrameFloor` elements (inferred to be floors) adjacent to conditioned space
Component Load: *: Slabs (MBtu)	Heat gain/loss through HPXML `Slab` elements adjacent to conditioned space
Component Load: *: Internal Mass (MBtu)	Heat gain/loss from internal mass (e.g., furniture, interior walls/floors) in conditioned space
Component Load: *: Infiltration (MBtu)	Heat gain/loss from airflow induced by stack and wind effects
Component Load: *: Natural Ventilation (MBtu)	Heat gain/loss from airflow through operable windows
Component Load: *: Mechanical Ventilation (MBtu)	Heat gain/loss from airflow/fan energy from mechanical ventilation systems (including clothes dryer exhaust)
Component Load: *: Whole House Fan (MBtu)	Heat gain/loss from airflow due to a whole house fan
Component Load: *: Ducts (MBtu)	Heat gain/loss from conduction and leakage losses through supply/return ducts outside conditioned space
Component Load: *: Internal Gains (MBtu)	Heat gain/loss from appliances, lighting, plug loads, water heater tank losses, etc. in the conditioned space

4.1.8 Annual Hot Water Uses

Current annual hot water uses are:

Type	Notes
Hot Water: Clothes Washer (gal)	
Hot Water: Dishwasher (gal)	
Hot Water: Fixtures (gal)	Showers and faucets.
Hot Water: Distribution Waste (gal)	

4.2 Timeseries Outputs

The measure will generate a timeseries CSV output file if the Timeseries Reporting Frequency argument is specified and one or more Generate Timeseries Output arguments are true. The timeseries output file is called results_timeseries.csv and co-located with the EnergyPlus output.

Depending on the outputs requested, CSV files may include:

Type	Notes
Fuel Consumptions	Energy use for each fuel type (in kBtu for fossil fuels and kWh for electricity).
End Use Consumptions	Energy use for each end use type (in kBtu for fossil fuels and kWh for electricity).
Hot Water Uses	Water use for each end use type (in gallons).
Total Loads	Heating and cooling loads (in kBtu) for the building.
Component Loads	Heating and cooling loads (in kBtu) disaggregated by component (e.g., Walls, Windows, Infiltration, Ducts, etc.).
Zone Temperatures	Average temperatures (in deg-F) for each space modeled (e.g., living space, attic, garage, basement, crawlspace, etc.).
Airflows	Airflow rates (in cfm) for infiltration, mechanical ventilation (including clothes dryer exhaust), natural ventilation, whole house fans.
Weather	Weather file data including outdoor temperatures, relative humidity, wind speed, and solar.

CHAPTER 5

Indices and tables

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