OpenStudio-ERI Documentation

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Introduction

The OpenStudio-ERI project allows calculating an Energy Rating Index (ERI) using the Department of Energy's open-source OpenStudio/EnergyPlus simulation platform. The building description is provided in an HPXML file format.

ERI is defined by ANSI/RESNET/ICC 301-2014© "Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index".

1.1 License

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Capabilities

2.1 ERI Capabilities

The following ERI Standards and Addenda are currently available:

- ANSI/RESNET/ICC 301-2014© "Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index".

- ANSI/RESNET/ICC 301-2014 Addendum A-2015, Domestic Hot Water Systems, January 15, 2016

- ANSI/RESNET/ICC 301-2014 Addendum D-2017, Duct Leakage to Outside Test Exception, January 1, 2018

- ANSI/RESNET/ICC 301-2014 Addendum E-2018, House Size Index Adjustment Factors, February 1, 2018

- ANSI/RESNET/ICC 301-2014 Addendum G-2018, Solid State Lighting, February 2, 2018

- ANSI/RESNET/ICC 301-2014 Addendum L-2018, Duct Leakage to Outside Test Exception, July 1, 2019

- ANSI/RESNET/ICC 301-2019 "Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index".

- ANSI/RESNET/ICC 301-2019 Addendum A-2019, Clothes Washers and Dryers and Dishwashers, July 1, 2020

2.2 Modeling Capabilities

The following building features/technologies are available for modeling:

- 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
        - ∗ Furnaces
        - ∗ Wall/Floor Furnaces
        - ∗ Stoves & Portable Heaters
        - ∗ Boilers
    - **–** Cooling Systems
        - ∗ Central Air Conditioners
        - ∗ Room Air Conditioners
        - ∗ Evaporative Coolers
        - ∗ 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 Type
    - **–** 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

– Low-Flow 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

- Whole House Fan

- Photovoltaics

- Appliances

– Clothes Washer

– Clothes Dryer

– Dishwasher

– Refrigerator

– Cooking Range/Oven

- Lighting

- Ceiling Fans

2.3 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. A number of such enhancements have been made to date.

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.

Getting Started

Here is a brief overview on getting setup, running an ERI calculation, and obtaining outputs.

3.1 Setup

To get started:

1. Either download OpenStudio 3.0.0 and install the Command Line Interface/EnergyPlus components, or use the nrel/openstudio docker image.

2. Download the OpenStudio-ERI v0.11.0 Beta release.

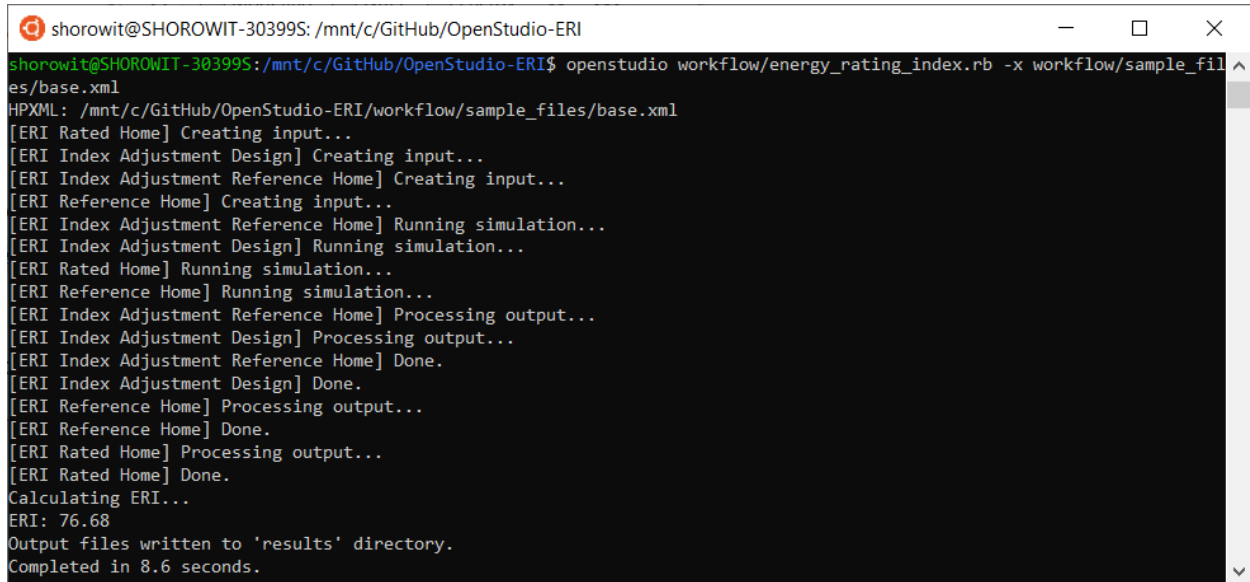3. To obtain all available weather files, run: `openstudio workflow/energy_rating_index.rb --download-weather`

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.

3.2 Running

Run the ERI calculation on a provided sample HPXML file as follows: `openstudio workflow/energy_rating_index.rb -x workflow/sample_files/base.xml`

Note that the Reference Home, Rated Home and Index Adjustment Home (if applicable) simulations will be executed in parallel on the local machine.

This will generate output as shown below:

You can also request generation of hourly output CSV files as part of the calculation by providing one or more `--hourly` flags.

To request all possible hourly outputs: `openstudio workflow/energy_rating_index.rb -x workflow/sample_files/base.xml --hourly ALL`

Or one or more specific hourly output types can be requested, e.g.: `openstudio workflow/ energy_rating_index.rb -x workflow/sample_files/base.xml --hourly fuels --hourly temperatures`

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

3.3 Output

Upon completion, ERI is provided in the console (stdout) as well as available in some of the summary output files. See the *Outputs* section for a description of all available outputs.

Software Connection

4.1 Introduction

OpenStudio-ERI 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.

4.2 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 an Energy Rating Index calculation.

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

1. Validation against the HPXML Schema

   The HPXML XSD Schema can be found at `hpxml-measures/HPXMLtoOpenStudio/resources/HPXML.xsd`. It should be used by the software developer to validate their HPXML file prior to running the workflow. 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-ERI **does not** validate the HPXML file against the XSD Schema and assumes the file submitted is valid.

2. Validation using Schematron

   The Schematron document for the ERI use case can be found at `rulesets/301EnergyRatingIndexRuleset/resources/301validator.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-ERI **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 Energy Rating Index calculations:

- Validation against XSD for general correctness and usage of HPXML

- Validation against Schematron for understanding XML document requirements specific to running ERI calculations

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4.3 HPXML Software Info

The version of the ERI calculation to be run is specified inside the HPXML file itself at `/HPXML/SoftwareInfo/extension/ERICalculation/Version`. For example, a value of "2014AE" tells the workflow to use ANSI/RESNET/ICC© 301-2014 with both Addendum A (Amendment on Domestic Hot Water Systems) and Addendum E (House Size Index Adjustment Factors) included. A value of "latest" can be used to always point to the latest version available.

Note: Valid choices for ERI version can be looked up in the ERI Use Case.

4.4 HPXML Building Details

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

4.5 HPXML Building Summary

This section describes elements specified in HPXML's `BuildingSummary`. It is used for high-level building information needed for an ERI calculation including conditioned floor area, number of bedrooms, number of conditioned floors, residential facility type, etc. Note that a walkout basement should be included in `NumberofConditionedFloorsAboveGrade`.

The `BuildingSummary/Site/FuelTypesAvailable` element is used to determine whether the home has access to natural gas or fossil fuel delivery (specified by any value other than "electricity"). This information may be used for determining the heating system, as specified by the ERI 301 Standard.

4.6 HPXML Weather Station

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

The `ClimateandRiskZones/ClimateZoneIECC` element specifies the IECC climate zone(s) for years required by the ERI 301 Standard.

The `ClimateandRiskZones/WeatherStation` element specifies the EnergyPlus weather file (EPW) to be used in the simulation. The weather file can be entered in one of two ways:

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1. Using `WeatherStation/WMO`, which must be one of the acceptable TMY3 WMO station numbers found in the `weather/data.csv` file. The full set of U.S. TMY3 weather files can be downloaded here.

2. Using `WeatherStation/extension/EPWFilePath`.

In addition to using the TMY3 weather files that are provided, custom weather files can be used if they are in EPW file format. To use custom weather files, first ensure that all weather files have a unique WMO station number (as provided in the first header line of the EPW file). Then place them in the `weather` directory and call `openstudio energy_rating_index.rb --cache-weather`. After processing is complete, each EPW file will have a corresponding *.csv cache file and the WMO station numbers of these weather files will be available in the *weather/data.csv'* file.

Note: In the future, we hope to provide an automated weather file selector based on a building's address/zipcode or similar information. But for now, each software tool is responsible for providing this information.

4.7 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 (not shared parking)	EnergyPlus calculation	Any
other housing unit	Unrated Conditioned Space	Same as conditioned space	Attached/Multifamily only
other heated space	Unrated Heated Space	Average of conditioned space and outside; minimum of 68F	Attached/Multifamily only
other multifamily buffer space	Multifamily Buffer Boundary	Average of conditioned space and outside; minimum of 50F	Attached/Multifamily only
other non-freezing space	Non-Freezing Space	Floats with outside; minimum of 40F	Attached/Multifamily only

> **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.

4.7.1 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. ACH50 (air changes per hour at 50Pa): Use `BuildingAirLeakage/UnitofMeasure='ACH'` and `HousePressure='50'`

3. CFM50 (cubic feet per minute at 50Pa): Use `BuildingAirLeakage/UnitofMeasure='CFM'` and `HousePressure='50'`

In addition, the building's volume associated with the air leakage measurement is provided in HPXML's `AirInfiltrationMeasurement/InfiltrationVolume`.

4.7.2 HPXML Attics

If the building has an unvented attic, an `Enclosure/Attics/Attic/AtticType/Attic[Vented='false']` element must be defined. It must have the `WithinInfiltrationVolume` element specified in accordance with ANSI/RESNET/ICC Standard 380.

If the building has a vented attic, an `Enclosure/Attics/Attic/AtticType/Attic[Vented='true']` element may be defined in order to specify the ventilation rate. The ventilation rate can be entered as a specific leakage area using `VentilationRate[UnitofMeasure='SLA']/Value` or as natural air changes per hour using `VentilationRate[UnitofMeasure='ACHnatural']/Value`. If the ventilation rate is not provided, the ERI 301 Standard Reference Home defaults will be used.

4.7.3 HPXML Foundations

If the building has an unconditioned basement, an `Enclosure/Foundations/Foundation/FoundationType/Basement[Conditioned='false']` element must be defined. It must have the `WithinInfiltrationVolume` element specified in accordance with ANSI/RESNET/ICC Standard 380.

If the building has an unvented crawlspace, an `Enclosure/Foundations/Foundation/FoundationType/Crawlspace[Vented='false']` element must be defined. It must have the `WithinInfiltrationVolume` element specified in accordance with ANSI/RESNET/ICC Standard 380.

If the building has a vented crawlspace, an `Enclosure/Foundations/Foundation/FoundationType/Crawlspace[Vented='true']` element may be defined in order to specify the ventilation rate. The ventilation rate can be entered as a specific leakage area using `VentilationRate[UnitofMeasure='SLA']/Value`. If the ventilation rate is not provided, the ERI 301 Standard Reference Home defaults will be used.

4.7.4 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`.

Beyond the specification of typical heat transfer properties (insulation R-value, solar absorptance, emittance, etc.), note that roofs can be defined as having a radiant barrier. If `RadiantBarrier` is provided, `RadiantBarrierGrade` must also be provided.

4.7.5 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.

4.7.6 HPXML Walls

Any wall that has no contact with the ground and bounds a space type should be specified as an `Enclosure/Walls/Wall`. Interior walls (for example, walls solely within the conditioned space of the building) are not required.

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

4.7.7 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.

4.7.8 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 `Insulation/AssemblyEffectiveRValue`.

4.7.9 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.

4.7.10 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.

Finally, windows must have the `FractionOperable` property specified for determining natural ventilation. 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).

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.

4.7.11 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.

4.7.12 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.

4.8 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.

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

4.8.1 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:

Heat-ingSys-temType	Is-SharedSys-tem	DistributionSystem	Heat-ingSystem-Fuel	Annual-HeatingEf-ficiency	Heating-Capacity
ElectricRe-sistance			electricity	Percent	(required)
Furnace		AirDistribution or DSE	<any>	AFUE	(required)
WallFurnace			<any>	AFUE	(required)
FloorFurnace			<any>	AFUE	(required)
Boiler	false	HydronicDistribution or DSE	<any>	AFUE	(required)
Boiler	true	HydronicDistribution or Hy-dronicAndAirDistribution	<any>	AFUE	
Stove			<any>	Percent	(required)
Portable-Heater			<any>	Percent	(required)
Fireplace			<any>	Percent	(required)

For all systems, 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 using the following inputs:

- `extension/SharedLoopWatts`: Shared pump power [W]

- `NumberofUnitsServed`: Number of units served by the shared system

- `extension/FanCoilWatts`: In-unit fan coil power [W]

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

For shared boilers connected to a water loop heat pump, an additional element is required:

- `extension/WaterLoopHeatPump/AnnualHeatingEfficiency[Units="COP"]/Value`: WLHP rated heating efficiency

4.8.2 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:

Cool-ingSys-temType	Is-SharedSys-tem	DistributionSystem	Cool-ingSys-temFuel	Annual-CoolingEffi-ciency	Sensible-HeatFrac-tion	Cooling-Capac-ity
central air conditioner		AirDistribution or DSE	electricity	SEER	(optional)	(re-quired)
room air conditioner			electricity	EER	(optional)	(re-quired)
evaporative cooler		AirDistribution or DSE (op-tional)	electricity			
chiller	true	HydronicDistribution or HydronicAndAirDistribu-tion	electricity	kW/ton		(re-quired)
cooling tower	true	HydronicAndAirDistribu-tion	electricity			

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

For shared chillers (i.e., serving multiple dwelling units), additional elements are required:

- `NumberofUnitsServed`: Number of units served by the shared system

- `AnnualCoolingEfficiency[Units="kW/ton"]/Value`: Chiller efficiency

- `extension/SharedLoopWatts`: Total of the pumping and fan power serving the system [W]

For shared chillers connected to a fan coil, additional elements are required:

- `extension/FanCoilWatts`: Total of the in-unit cooling equipment power serving the unit [W]

For shared chillers connected to a water loop heat pump, additional elements are required:

- `extension/WaterLoopHeatPump/CoolingCapacity`: WLHP cooling capacity [Btu/hr]

- `extension/WaterLoopHeatPump/AnnualCoolingEfficiency[Units="EER"]/Value`: WLHP rated cooling efficiency

For shared cooling towers (which must always be connected to a water loop heat pump), additional elements are required:

- `NumberofUnitsServed`: Number of units served by the shared system

- `extension/SharedLoopWatts`: Total of the pumping and fan power serving the system [W]

- `extension/WaterLoopHeatPump/CoolingCapacity`: WLHP cooling capacity [Btu/hr]

- `extension/WaterLoopHeatPump/AnnualCoolingEfficiency[Units="EER"]/Value`: WLHP rated cooling efficiency

4.8.3 HPXML Heat Pumps

Each heat pump should be entered as a `Systems/HVAC/HVACPlant/HeatPump`. Inputs includ-ing `HeatPumpType`, `CoolingCapacity`, `HeatingCapacity`, `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:

Heat-Pump-Type	Is-SharedSystem	Distribution-System	Heat-Pump-Fuel	Annual-CoolingEfficiency	Annual-HeatingEfficiency	CoolingSensibleHeatFraction	Heating-Capacity17F
air-to-air		AirDistribution or DSE	electricity	SEER	HSPF	(optional)	(optional)
mini-split		AirDistribution or DSE (optional)	electricity	SEER	HSPF	(optional)	(optional)
ground-to-air	false	AirDistribution or DSE	electricity	EER	COP	(optional)	
ground-to-air	true	AirDistribution or DSE	electricity	EER	COP	(optional)	

Ground-to-air heat pumps also have an additional input:

- `extension/PumpPowerWattsPerTon`: Ground loop circulator pump power during operation of the heat pump in Watts/ton of cooling capacity.

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 heat pump has backup heating, it can be specified with `BackupSystemFuel`, `BackupAnnualHeatingEfficiency`, and `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 the `BackupHeatingSwitchoverTemperature` is not provided, the backup heating system will operate as needed when the heat pump has insufficient capacity.

For multiple ground source heat pumps on a shared hydronic circulation loop (`IsSharedSystem="true"`), additional elements are required:

- `NumberofUnitsServed`: Number of units served by the shared system

- `extension/SharedLoopWatts`: Shared pump power [W]

4.8.4 HPXML HVAC Control

A `Systems/HVAC/HVACControl` must be provided if any HVAC systems are specified. Its `ControlType` specifies whether there is a manual or programmable thermostat.

4.8.5 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 supply ducts (`Ducts[DuctType='supply']`) - Optional return ducts (`Ducts[DuctType='return']`)

Each duct must have `DuctInsulationRValue`, `DuctLocation`, and `DuctSurfaceArea` provided.

`DuctLocation` must be 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
crawlspace - unvented		EnergyPlus calculation	Any
crawlspace - vented		EnergyPlus calculation	Any
attic - unvented		EnergyPlus calculation	Any
attic - vented		EnergyPlus calculation	Any
garage	Single-family (not shared parking)	EnergyPlus calculation	Any
exterior wall		Average of conditioned space and outside	Any
under slab		Ground	Any
roof deck		Outside	Any
outside		Outside	Any
other housing unit	Unrated Conditioned Space	Same as conditioned space	Attached/Multifamily only
other heated space	Unrated Heated Space	Average of conditioned space and outside; minimum of 68F	Attached/Multifamily only
other multifamily buffer space	Multifamily Buffer Boundary	Average of conditioned space and outside; minimum of 50F	Attached/Multifamily only
other non-freezing space	Non-Freezing Space	Floats with outside; minimum of 40F	Attached/Multifamily only

AirDistribution systems must also have duct leakage testing provided in one of three ways:

1. Optional supply/return leakage to the outside: `DuctLeakageMeasurement[DuctType="supply" or DuctType="return"]/DuctLeakage[Units="CFM25"][TotalOrToOutside="to outside"]/Value`

2. Total leakage: `DuctLeakageMeasurement/DuctLeakage[Units="CFM25"][TotalOrToOutside="total"]/Value` (Version 2014AD or newer)

3. Leakage testing exemption: `extension/DuctLeakageToOutsideTestingExemption="true"` (Version 2014ADEGL or newer)

Note: When the leakage to outside testing exemption is used with Addendum L or newer, it effectively overrides the Addendum D specification such that the leakage to outside testing exemption reflects solely the Addendum L

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specification.

> **Warning:** Total leakage and leakage to outside testing exemption should only be used if the conditions specified in ANSI/RESNET/ICC 301 have been appropriately met.

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 `AnnualHeatingDistributionSystemEfficiency` and `AnnualCoolingDistributionSystemEfficiency` elements.

4.8.6 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 systems 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`, `HoursInOperation`, and `IsSharedSystem` 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`.

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

- `TestedFlowRate`: The measured airflow rate. If unmeasured, provide `extension/FlowRateNotTested[text()="true"]` instead. 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 unknown, provide `extension/FanPowerDefaulted[text()="true"]` instead.

If the ventilation system is shared (i.e., serving multiple dwelling units), the following inputs are available:

- `RatedFlowRate`: The rated airflow rate of the entire system.

- `FanPower`: The fan power for the entire system at highest airflow setting. If unknown, provide `extension/FanPowerDefaulted[text()="true"]` instead.

- `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. If unmeasured, provide `extension/FlowRateNotTested[text()="true"]` instead.

- `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.

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).

4.8.7 HPXML Water Heating Systems

Each water heater should be entered as a `Systems/WaterHeating/WaterHeatingSystem`. Inputs including `WaterHeaterType`, `IsSharedSystem`, `Location`, 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).

The `Location` must be 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 (not shared parking)	EnergyPlus calculation	Any
crawlspace - unvented		EnergyPlus calculation	Any
crawlspace - vented		EnergyPlus calculation	Any
other exterior	Outside	Outside	Any
other housing unit	Unrated Conditioned Space	Same as conditioned space	Attached/Multifamily only
other heated space	Unrated Heated Space	Average of conditioned space and outside; minimum of 68F	Attached/Multifamily only
other multifamily buffer space	Multifamily Buffer Boundary	Average of conditioned space and outside; minimum of 50F	Attached/Multifamily only
other non-freezing space	Non-Freezing Space	Floats with outside; minimum of 40F	Attached/Multifamily only

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

Water-HeaterType	UniformEnergyFactor or EnergyFactor	FuelType	TankVolume	Heating-Capacity	RecoveryEfficiency	UsesDesuperheater	Water-HeaterInsulation/Jacket/JacketRValue	Related-HVACSystem
storage water heater	required	<any>	required	(optional)	required if non-electric	(optional)	(optional)	required if uses desuperheater
instantaneous water heater	required	<any>				(optional)		required if uses desuperheater
heat pump water heater	required	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 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`.

If the water heater is a shared system (i.e., serving multiple dwelling units or a shared laundry room), it should be described using `IsSharedSystem='true'`. In addition, the `NumberofUnitsServed` must be specified, where the value is the number of dwelling units served either indirectly (e.g., via shared laundry room) or directly.

4.8.8 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 is required:

- `PipingLength`: 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)

Recirculation

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

- `ControlType`: One of "manual demand control", "presence sensor demand control", "temperature", "timer", or "no control".

- `RecirculationPipingLoopLength`: 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`: 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`: Pump power in Watts.

Shared Recirculation

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

- `extension/SharedRecirculation/NumberofUnitsServed`: Number of dwelling units served by the shared pump.

- `extension/SharedRecirculation/PumpPower`: Shared pump power in Watts.

- `extension/SharedRecirculation/ControlType`: One of "manual demand control", "presence sensor demand control", "timer", or "no control".

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

4.8.9 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.

4.8.10 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`

- `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`

- `ConnectedTo`: Must point to a `WaterHeatingSystem`. The connected water heater cannot be of type space-heating boiler or attached to a desuperheater.

4.8.11 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:

- `IsSharedSystem`: true or false

- `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`

- `InverterEfficiency`: Default is 0.96.

- `SystemLossesFraction`: Default is 0.14. System losses include soiling, shading, snow, mismatch, wiring, degradation, etc.

If the PV system is a shared system (i.e., serving multiple dwelling units), it should be described using `IsSharedSystem='true'`. In addition, 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.

4.9 HPXML Appliances

This section describes elements specified in HPXML's `Appliances`. Many of the appliances' inputs are derived from EnergyGuide labels.

The `Location` for each appliance must be 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 (not shared parking)	Any
other housing unit	Unrated Conditioned Space	Attached/Multifamily only
other heated space	Unrated Heated Space	Attached/Multifamily only
other multifamily buffer space	Multifamily Buffer Boundary	Attached/Multifamily only
other non-freezing space	Non-Freezing Space	Attached/Multifamily only

4.9.1 HPXML Clothes Washer

A single `Appliances/ClothesWasher` element may be specified. The `IsSharedAppliance` element must be provided.

If no clothes washer is located within the Rated Home, a clothes washer in the nearest shared laundry room on the project site shall be used if available for daily use by the occupants of the Rated Home. If there are multiple clothes washers, the clothes washer with the highest Label Energy Rating (kWh/yr) shall be used.

The efficiency of the clothes washer can either be entered as an `IntegratedModifiedEnergyFactor` or a `ModifiedEnergyFactor`. Several other inputs from the EnergyGuide label must be provided as well.

If the clothes washer is a shared appliance (i.e., in a shared laundry room), it should be described using `IsSharedAppliance='true'`. In addition, the following elements must be provided:

- `AttachedToWaterHeatingSystem`: Reference a shared water heater.

- `NumberofUnitsServed`: The number of dwelling units served by the shared laundry room.

- `NumberofUnits`: The number of clothes washers in the shared laundry room.

4.9.2 HPXML Clothes Dryer

A single `Appliances/ClothesDryer` element may be specified. The `IsSharedAppliance` element must be provided.

If no clothes dryer is located within the Rated Home, a clothes dryer in the nearest shared laundry room on the project site shall be used if available for daily use by the occupants of the Rated Home. If there are multiple clothes dryers, the clothes dryer with the lowest Energy Factor or Combined Energy Factor shall be used.

The dryer's `FuelType` and `ControlType` ("timer" or "moisture") must be provided. The efficiency of the clothes dryer can either be entered as a `CombinedEnergyFactor` or an `EnergyFactor`.

If the clothes dryer is a shared appliance (i.e., in a shared laundry room), it should be described using `IsSharedAppliance='true'`. In addition, the following elements must be provided:

- `NumberofUnitsServed`: The number of dwelling units served by the shared laundry room.

- `NumberofUnits`: The number of clothes dryers in the shared laundry room.

4.9.3 HPXML Dishwasher

A single `Appliances/Dishwasher` element may be specified. The `IsSharedAppliance` element must be provided.

If no dishwasher is located within the Rated Home, a dishwasher in the nearest shared kitchen in the building shall be used only if available for daily use by the occupants of the Rated Home. If there are multiple dishwashers, the dishwasher with the lowest Energy Factor (highest kWh/yr) shall be used.

The efficiency of the dishwasher can either be entered as a `RatedAnnualkWh` or an `EnergyFactor`. The dishwasher's `PlaceSettingCapacity` also must be provided as well as other inputs from the EnergyGuide label.

If the dishwasher is a shared appliance (i.e., in a shared laundry room), it should be described using `IsSharedAppliance='true'`. In addition, the following elements must be provided:

- `AttachedToWaterHeatingSystem`: Reference a shared water heater.

4.9.4 HPXML Refrigerator

A single `Appliances/Refrigerator` element may be specified.

If there are multiple refrigerators, the total energy consumption of all refrigerators/freezers shall be used along with the location that represents the majority of power consumption.

The efficiency of the refrigerator must be entered as `RatedAnnualkWh`.

4.9.5 HPXML Cooking Range/Oven

A single pair of `Appliances/CookingRange` and `Appliances/Oven` elements may be specified.

The `FuelType` of the range and whether it `IsInduction`, as well as whether the oven `IsConvection`, must be provided.

4.10 HPXML Lighting

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

4.10.1 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`
- `LightingGroup/Location`: 'interior', 'garage', and 'exterior'

Use `LightEmittingDiode` for Tier II qualifying light fixtures; use `CompactFluorescent` and/or `FluorescentTube` for Tier I qualifying light fixtures.

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.

4.10.2 HPXML Ceiling Fans

Each ceiling fan (or set of identical ceiling fans) should be entered as a `Lighting/CeilingFan`. The `Airflow/Efficiency` (at medium speed) and `Quantity` must be provided.

4.11 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 ERI Use Case).

2. An unexpected error occurred in the workflow (e.g., applying the ERI 301 ruleset).

3. An unexpected EnergyPlus simulation error occurred.

If, for example, the Rated Home is unsuccessful, first look in the ERIRatedHome/run.log for details. If there are no errors in that log file, then the error may be in the EnergyPlus simulation – see ERIRatedHome/eplusout.err.

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

4.12 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.

Outputs

Upon completion of the ERI calculation, summary output files and simulation files are available. See the sample_results directory for examples of these outputs.

5.1 Summary Files

Several summary files described below are found in the `results` directory.

5.1.1 ERI_Results.csv

The `ERI_Results.csv` file includes the ERI result as well as the high-level components (e.g., REUL, EC_r, EC_x, IAD_Save) that comprise the ERI calculation. The file reflects the format of the Results tab of the HERS Method Test spreadsheet.

Note that multiple comma-separated values will be reported for many of these outputs if there are multiple heating, cooling, or hot water systems.

See the example ERI_Results.csv.

5.1.2 ERI_Worksheet.csv

The `ERI_Worksheet.csv` file includes more detailed components that feed into the ERI_Results.csv values. The file reflects the formate of the Worksheet tab of the HERS Method Test spreadsheet.

Note that multiple comma-separated values will be reported for many of these outputs if there are multiple heating, cooling, or hot water systems.

See the example ERI_Worksheet.csv.

5.1.3 ERI_____Home.csv

A CSV file is written for each of the homes simulated (e.g., `ERIReferenceHome.csv` for the Reference home). The CSV file includes the following sections of output.

See the example ERIRatedHome.csv.

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)	
Propane: Total (MBtu)	
Wood: Total (MBtu)	Currently unused for ERI.
Wood Pellets: Total (MBtu)	Currently unused for ERI.

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)	Shared ventilation preconditioning system.
Electricity: Mech Vent Precooling (MBtu)	Shared ventilation preconditioning system.
Electricity: Whole House Fan (MBtu)	
Electricity: Refrigerator (MBtu)	
Electricity: Dehumidifier (MBtu)	Currently unused for ERI.
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: PV (MBtu)	
Natural Gas: Heating (MBtu)	

Table 1 – continued from previous page

Type	Notes
Natural Gas: Hot Water (MBtu)	
Natural Gas: Clothes Dryer (MBtu)	
Natural Gas: Range/Oven (MBtu)	
Natural Gas: Mech Vent Preheating (MBtu)	Shared ventilation preconditioning system.
Fuel Oil: Heating (MBtu)	
Fuel Oil: Hot Water (MBtu)	
Fuel Oil: Clothes Dryer (MBtu)	
Fuel Oil: Range/Oven (MBtu)	
Fuel Oil: Mech Vent Preheating (MBtu)	Shared ventilation preconditioning system.
Propane: Heating (MBtu)	
Propane: Hot Water (MBtu)	
Propane: Clothes Dryer (MBtu)	
Propane: Range/Oven (MBtu)	
Propane: Mech Vent Preheating (MBtu)	Shared ventilation preconditioning system.
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)	Shared ventilation preconditioning system.
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)	Shared ventilation preconditioning system.

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.

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.

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.

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.

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 a whole house mechanical ventilation system
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

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)	

5.1.4 ERI_____Home_Hourly.csv

See the *Running* section for requesting hourly outputs. When requested, a CSV file of hourly outputs is written for the Reference/Rated Homes (e.g., `ERIReferenceHome_Hourly.csv` for the Reference home).

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, natural ventilation, and whole house fans.
Weather	Weather file data including outdoor temperatures, relative humidity, wind speed, and solar.

See the example ERIRatedHome_Hourly.csv.

5.1.5 ERI_____Home.xml

A HPXML file is written for each of the homes simulated (e.g., `ERIReferenceHome.xml` for the Reference home). The file reflects the configuration of the home after applying the ERI 301 ruleset.

See the example ERIRatedHome.xml.

5.2 Simulation Files

In addition, raw EnergyPlus simulation input/output files are available for each simulation (e.g., `ERIRatedHome`, `ERIReferenceHome`, etc. directories).

Warning: It is highly discouraged for software tools to read the raw EnergyPlus output files. The EnergyPlus input/output files are made available for inspection, but the outputs for certain situations can be misleading if one does not know how the model was created. If there are additional outputs of interest that are not available in our summary output files, please send us a request.

See the example ERIRatedHome directory.

Testing Framework

A large number of tests are automatically run for every code change in the GitHub repository.

The current set of tests include:

- Successful ERI calculations for all sample files
- RESNET® ANSI/ASHRAE Standard 140-2011, Class II, Tier 1 Tests
- RESNET HERS® Reference Home auto-generation tests
- RESNET HERS Index Adjustment Design auto-generation tests
- RESNET HERS method tests
- RESNET HVAC tests
- RESNET Duct distribution system efficiency tests
- RESNET Hot water system performance tests

If you are seeking to develop RESNET Accredited Rating Software, you will need to submit your final software product to RESNET for accreditation.

6.1 Running Tests Locally

All tests can be run locally using: `openstudio energy_rating_index_test.rb`

Individual tests (any method in workflow/tests/energy_rating_index_test.rb that begins with "test_") can also be run. For example: `openstudio energy_rating_index_test.rb --name=test_resnet_hers_method`

Test results in CSV format are created at workflow/tests/test_results. For many RESNET tests, the Excel spreadsheet test criteria are also implemented in code to automate the process of checking for test failures. All simulation/HPXML/etc. files generated from running the tests can be found inside the workflow/tests/test_files directory.

At the completion of the test, there will also be output that denotes the number of failures/errors like so:

```
Finished in 36.067116s, 0.0277 runs/s, 0.9704 assertions/s.          1 runs, 35
assertions, 0 failures, 0 errors, 0 skips
```

Software developers may find it convenient to export HPXML files with the same name as the test files included in the repository. This allows issuing the same commands above to generate test results.

CHAPTER 7

Packaging

The OpenStudio-ERI workflow is cross-platform and can be used in web or desktop applications.

7.1 Web Applications

Using the OpenStudio-ERI workflow in a web application is very straightforward.

First, OpenStudio must be available. Web applications may wish to use the nrel/openstudio docker image. Alternatively, the OpenStudio installer can be executed on the web server – only the EnergyPlus and Command Line Interface (CLI) components are required.

Then grab the latest OpenStudio-ERI release.

7.2 Desktop Applications

The OpenStudio-ERI workflow can also be packaged into a third-party software installer for distribution to desktop users.

First, OpenStudio must be bundled – only the EnergyPlus and Command Line Interface (CLI) components are required. Either the OpenStudio setup file can be automatically run as part of your install, or the OpenStudio application can be installed to a local computer and its contents can be re-bundled in your installer (there are no external dependencies required). The only required OpenStudio contents are the `openstudio/bin` and `openstudio/EnergyPlus` directories.

Then grab the latest OpenStudio-ERI release.

Indices and tables

- genindex
- search