
OpenStudio-ERI Documentation

Scott Horowitz

Jul 23, 2019

Contents:

1	Introduction	1
1.1	License	1
1.2	Disclaimer	1
2	Capabilities	3
2.1	ERI Capabilities	3
2.2	Modeling Capabilities	3
2.3	Accuracy vs Speed	5
3	Getting Started	7
3.1	Setup	7
3.2	Running	7
3.3	Outputs	8
4	Software Connection	9
4.1	HPXML Overview	9
4.2	ERI Use Case for HPXML	9
4.3	Validating & Debugging Errors	18
4.4	Sample Files	18
5	Testing Framework	19
5.1	Types of Tests	19
5.2	Test Results	19
5.3	Running Tests Locally	20
6	Indices and tables	21

CHAPTER 1

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

This workflow 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](#).

1.2 Disclaimer

Downloading and using this software from this website does not constitute accreditation of the final software product by RESNET. If you are seeking to develop RESNET Accredited Rating Software, you will need to submit your final software product to RESNET for accreditation.

Any reference herein to RESNET, its activities, products, or services, or any linkages from this website to RESNET’s website, does not constitute or imply the endorsement, recommendation, or favoring of the U.S. Government, the Alliance for Sustainable Energy, or any of their employees or contractors acting on their behalf.

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 E-2018, House Size Index Adjustment Factors, February 1, 2018
- ANSI/RESNET/ICC 301-2014 Addendum G-2018, Solid State Lighting, February 2, 2018

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 Furnaces & Stoves
 - * Boilers
 - Cooling Systems
 - * Central Air Conditioners
 - * Room Air Conditioners
 - Heat Pumps
 - * Air Source Heat Pumps
 - * Mini Split Heat Pumps
 - * Ground Source Heat Pumps
 - Thermostat Type
 - Ducts
- Water Heating
 - Water Heaters
 - * Storage Tank
 - * Instantaneous Tankless
 - * Heat Pump Water Heater
 - 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
- 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 tradeoffs 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. A number of 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.
- Use the `--no-ssl` flag to prevent SSL initialization in OpenStudio.
- Use the `-s` flag to skip HPXML validation.
- Run on computing environments with 1) fast CPUs, 2) sufficient memory, and 3) enough processors to allow all simulations to run in parallel.

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 2.8.1](#)) and install the Command Line Interface/EnergyPlus components, or use the [nrel/openstudio docker image](#).
2. Clone or download the [OpenStudio-ERI GitHub repository](#).
3. To obtain all available weather files, run: `openstudio workflow/energy_rating_index.rb --download-weather`

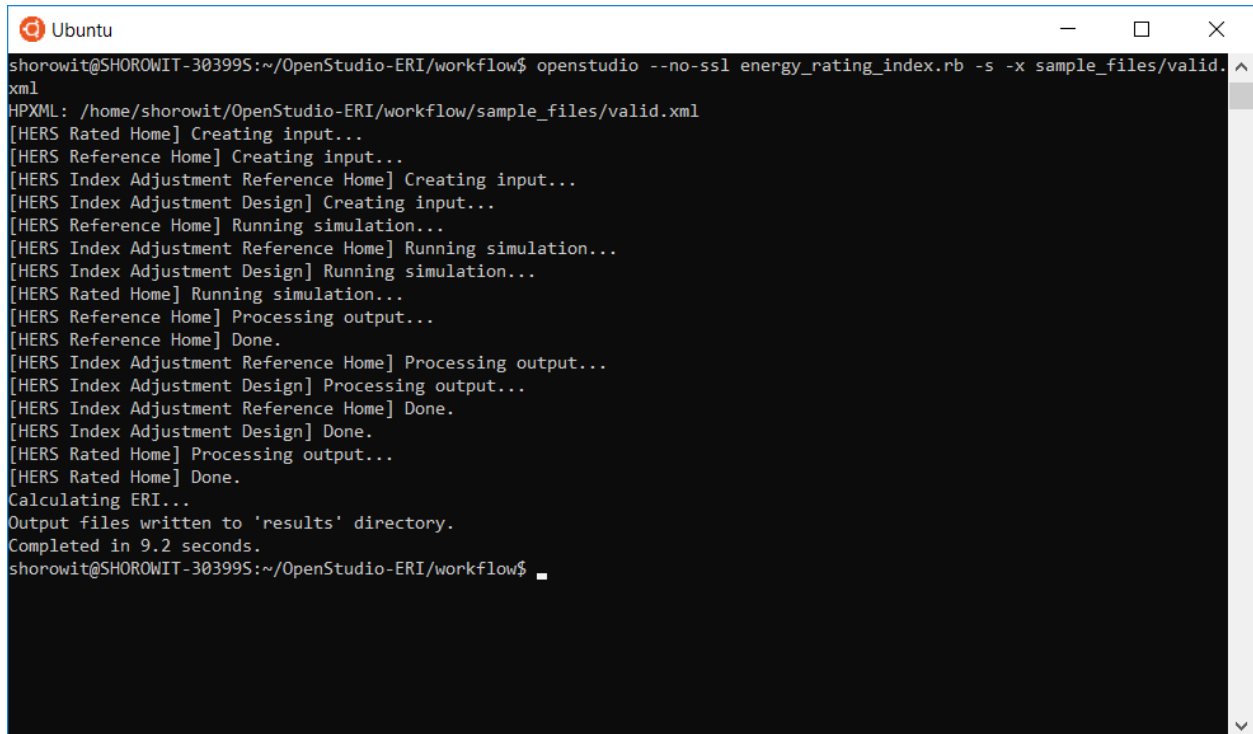
Note: If the `openstudio` command is not found, it's because the executable is not in your `PATH`. Either add the executable to your `PATH` or point directly to the executable found in the `openstudio-X.X.X/bin` directory.

3.2 Running

Run the ERI calculation on a provided sample HPXML file as follows: `openstudio --no-ssl workflow/energy_rating_index.rb -x workflow/sample_files/valid.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:



```
shorowit@SHOROWIT-30399S:~/OpenStudio-ERI/workflow$ openstudio --no-ssl energy_rating_index.rb -s -x sample_files/valid.xml
HPXML: /home/shorowit/OpenStudio-ERI/workflow/sample_files/valid.xml
[HERS Rated Home] Creating input...
[HERS Reference Home] Creating input...
[HERS Index Adjustment Reference Home] Creating input...
[HERS Index Adjustment Design] Creating input...
[HERS Reference Home] Running simulation...
[HERS Index Adjustment Reference Home] Running simulation...
[HERS Index Adjustment Design] Running simulation...
[HERS Rated Home] Running simulation...
[HERS Reference Home] Processing output...
[HERS Reference Home] Done.
[HERS Index Adjustment Reference Home] Processing output...
[HERS Index Adjustment Design] Processing output...
[HERS Index Adjustment Reference Home] Done.
[HERS Index Adjustment Design] Done.
[HERS Rated Home] Processing output...
[HERS Rated Home] Done.
Calculating ERI...
Output files written to 'results' directory.
Completed in 9.2 seconds.
shorowit@SHOROWIT-30399S:~/OpenStudio-ERI/workflow$
```

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

3.3 Outputs

Upon completion, multiple outputs are currently available:

- Summary `ERI_Results.csv` and `ERI_Worksheet.csv` files
- Summary annual energy consumption by fuel type and/or end use
- Reference/Rated/IndexAdjustment Home HPXML files (transformations of the input HPXML file as a result of applying the ERI 301 ruleset)
- EnergyPlus input/output files

See the [sample_results](#) directory for examples of these outputs.

Software Connection

In order to connect a software tool to the OpenStudio-ERI workflow, the software tool must be able to export its building description in [HPXML file](#) format.

4.1 HPXML Overview

HPXML is an open data standard for collecting and transferring home energy data. Requiring HPXML files as the input to the ERI workflow significantly reduces the complexity and effort for software developers to leverage the EnergyPlus simulation engine. It also simplifies the process of applying the ERI 301 ruleset.

The [HPXML Toolbox website](#) provides several resources for software developers, including:

1. An interactive schema validator
2. A data dictionary
3. An implementation guide

4.2 ERI Use Case for HPXML

HPXML is an flexible and extensible format, where nearly all fields in the schema are optional and custom fields can be included. Because of this, an ERI Use Case for HPXML has been developed that specifies the HPXML fields or enumeration choices required to run the workflow.

Software developers should use the [ERI Use Case](#) (defined as a set of conditional XPath expressions) as well as the [HPXML schema](#) to construct valid HPXML files for ERI calculations.

4.2.1 ERI Version

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.

Note: Valid choices for ERI version can be looked up in the [ERI Use Case](#).

4.2.2 Building Details

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

4.2.3 Building Summary

This section describes fields 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, etc.

The `BuildingSummary/Site/FuelTypesAvailable` field 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.

4.2.4 Climate and Weather

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

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

`ClimateandRiskZones/WeatherStation` specifies the EnergyPlus weather file (EPW) to be used in the simulation. The `WeatherStation/WMO` must be one of the acceptable WMO station numbers found in the [weather/data.csv](#) file.

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

4.2.5 Enclosure

This section describes fields 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	Notes
living space	Above-grade conditioned floor area.
attic - vented	
attic - unvented	
basement - conditioned	Below-grade conditioned floor area.
basement - unconditioned	
crawlspace - vented	
crawlspace - unvented	
garage	
other housing unit	Used to specify adiabatic surfaces.

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 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.

Air Leakage

Building air leakage characterized by air changes per hour or cfm at 50 pascals pressure difference (ACH50) is entered at `Enclosure/AirInfiltration/AirInfiltrationMeasurement/BuildingAirLeakage/AirLeakage`. The `Enclosure/AirInfiltration/AirInfiltrationMeasurement` should be specified with `HousePressure='50'` and `BuildingAirLeakage/UnitofMeasure='ACH'` or `BuildingAirLeakage/UnitofMeasure='CFM'`.

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

Vented Attics/Crawlspaces

The ventilation rate for vented attics (or 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 use the `VentilationRate[UnitofMeasure='SLA']/Value` element to specify a specific leakage area (SLA). If these elements are not provided, the ERI 301 Standard Reference Home defaults will be used.

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 `Floor` 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.

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.

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.

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. A continuous insulation layer with `NominalRValue` and `DistanceToBottomOfInsulation`. An insulation layer is 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). When an insulation layer R-value is specified, it is modeled with a concrete wall (whose `Thickness` is provided) as well as air film resistances as appropriate.

Option 2. An `AssemblyEffectiveRValue`. When instead providing an assembly effective R-value, the 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.

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 are primarily defined by their `Insulation/AssemblyEffectiveRValue`.

Slabs

Any space type that borders the ground should include an `Enclosure/Slabs/Slab` surface with the appropriate `InteriorAdjacentTo`. This includes basements, crawlspace (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 depth (`UnderSlabInsulationWidth`) or can span the entire slab (`UnderSlabInsulationSpansEntireSlab`).

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.

Overhangs 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.

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.

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.

4.2.6 Systems

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

If any HVAC systems are entered that provide heating, the sum of all their `FractionHeatLoadServed` values must equal 1. The same holds true for `FractionCoolLoadServeds` for HVAC systems that provide cooling and `FractionDHWLoadServed` for water heating systems.

Heating Systems

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

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

HeatingSystemType	DistributionSystem	HeatingSystemFuel	AnnualHeatingEfficiency
ElectricResistance		electricity	Percent
Furnace	AirDistribution or DSE	<any>	AFUE
WallFurnace		<any>	AFUE
Boiler	HydronicDistribution or DSE	<any>	AFUE
Stove		<any>	Percent

If a non-electric heating system is specified, the `ElectricAuxiliaryEnergy` element may be provided if available.

Cooling Systems

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

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

CoolingSystemType	DistributionSystem	CoolingSystemFuel	AnnualCoolingEfficiency
central air conditioner	AirDistribution or DSE	electricity	SEER
room air conditioner		electricity	EER

Heat Pumps

Each heat pump should be entered as a `Systems/HVAC/HVACPlant/HeatPump`. Inputs including `HeatPumpType`, `CoolingCapacity`, `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 required:

HeatPump-Type	DistributionSystem	HeatPump-Fuel	AnnualCoolingEfficiency	AnnualHeatingEfficiency
air-to-air	AirDistribution or DSE	electricity	SEER	HSPF
mini-split	AirDistribution or DSE (optional)	electricity	SEER	HSPF
ground-to-air	AirDistribution or DSE	electricity	EER	COP

If the heat pump has backup heating, it can be specified with `BackupSystemFuel` (currently only electricity is allowed), `BackupAnnualHeatingEfficiency` (percent), and `BackupHeatingCapacity`.

Thermostat

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

HVAC Distribution

Each separate HVAC distribution system should be specified as a `Systems/HVAC/HVACDistribution`. 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 are not allowed to be attached to a distribution system.

`AirDistribution` systems are defined by:

- Supply & return leakages in CFM25 to the outside (`DuctLeakageMeasurement/DuctLeakage/Value`)
- One or more supply & return ducts (`Ducts`)

For each duct, `DuctInsulationRValue`, `DuctLocation`, and `DuctSurfaceArea` must be provided.

`HydronicDistribution` systems do not require any additional inputs.

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

Mechanical Ventilation

A single whole-house mechanical ventilation system may be specified as a `Systems/MechanicalVentilation/VentilationFans/VentilationFan` with `UsedForWholeBuildingVentilation='true'`. Inputs including `FanType`, `RatedFlowRate`, `HoursInOperation`, and `FanPower` 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.

In many situations, the rated flow rate should be the value derived from actual testing of the system. For a CFIS system, the rated flow rate should equal the amount of outdoor air provided to the distribution system.

Water Heaters

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

heater efficiency should be provided as either an `EnergyFactor` or `UniformEnergyFactor`.

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

WaterHeaterType	FuelType	TankVolume	HeatingCapacity	RecoveryEfficiency
storage water heater	<any>	required	required	required if non-electric
instantaneous water heater	<any>			
heat pump water heater	electricity	required		

Hot Water Distribution

A `Systems/WaterHeating/HotWaterDistribution` must be provided if any water heating systems are specified. Inputs including `SystemType` and `PipeInsulation/PipeRValue` must be provided.

For a `SystemType/Standard` (non-recirculating) system, the following field is required:

- `PipingLength`: Measured length of hot water piping from the hot water heater 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)

For a `SystemType/Recirculation` system, the following fields are required:

- `ControlType`
- `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`

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

- `FacilitiesConnected`: ‘all’ if all of the showers in the home are connected to DWHR units; ‘one’ if if there are 2 or more showers in the home and only 1 shower is connected to a DWHR unit
- `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

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.

Photovoltaics

Each solar electric (photovoltaic) system should be entered as a `Systems/Photovoltaics/PVSystem`. The following fields, 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`
- `InverterEfficiency`: Default is 0.96.
- `SystemLossesFraction`: Default is 0.14. System losses include soiling, shading, snow, mismatch, wiring, degradation, etc.

4.2.7 Appliances

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

The `Location` for clothes washers, clothes dryers, and refrigerators can be provided, while dishwashers and cooking ranges are assumed to be in the living space.

Clothes Washer

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

Clothes Dryer

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

Dishwasher

An `Appliances/Dishwasher` element must be specified. The dishwasher's `PlaceSettingCapacity` must be provided. The efficiency of the dishwasher can either be entered as an `EnergyFactor` or `RatedAnnualkWh`.

Refrigerator

An `Appliances/Refrigerator` element must be specified. The efficiency of the refrigerator must be entered as `RatedAnnualkWh`.

Cooking Range/Oven

`Appliances/CookingRange` and `Appliances/Oven` elements must be specified. The `FuelType` of the range and whether it `IsInduction`, as well as whether the oven `IsConvection`, must be provided.

4.2.8 Lighting

The building's lighting is described by six `Lighting/LightingGroup` elements, each of which is the combination of:

- `LightingGroup/ThirdPartyCertification`: 'ERI Tier I' (fluorescent) and 'ERI Tier II' (LEDs, outdoor lamps controlled by photocells, or indoor lamps controlled by motion sensor)
- `LightingGroup/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. Garage lighting values are ignored if the building has no garage.

4.2.9 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.

4.3 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/epplusout.err`.

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

4.4 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.

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

5.1 Types of Tests

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

5.2 Test Results

Test results in CSV format can be found on the [CI machine](#) for any build under the “Artifacts” tab.

If you are seeking to develop RESNET Accredited Rating Software, you will need to submit your final software product to RESNET for accreditation. Note that EnergyPlus cannot currently pass the ANSI/ASHRAE Standard 140-2011 tests, for which test criteria were set by decades old simulation engines. There have been discussions about updating the test criteria using EnergyPlus and other modern simulation engines, but nothing has been done to date. In order to apply for RESNET accreditation, software developers will need to use the “Process for Exceptions and Appeals” in the Procedures for Verification of RESNET Accredited HERS Software Tools document.

5.3 Running Tests Locally

Tests can also be run locally, as shown below. Individual tests (any method in workflow/tests/energy_rating_index_test.rb that begins with “test_”) can also be run. For example:

- All tests: `openstudio energy_rating_index_test.rb`
- Method tests only: `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 6

Indices and tables

- `genindex`
- `search`