# OpenStudio-ERI Documentation

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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".

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CHAPTER 2

# 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 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
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    - Windows & Overhangs
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    - Doors
- HVAC
    - Heating Systems
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  - Clothes Dryer
  - Dishwasher
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  - 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.
- Use the `--no-ssl` flag to prevent SSL initialization in OpenStudio.
- Use the `-s` flag to skip HPXML validation.
- Do not use the `--hourly-output` flag unless hourly output is required.
- Run on computing environments with 1) fast CPUs, 2) sufficient memory, and 3) enough processors to allow all simulations to run in parallel.

# CHAPTER 3

# 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 2.9.0 and install the Command Line Interface/EnergyPlus components, or use the nrel/openstudio docker image.
2. Download the OpenStudio-ERI v0.6.0 Beta release.
3. To obtain all available weather files, run: `openstudio workflow/energy_rating_index.rb --download-weather`

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**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.

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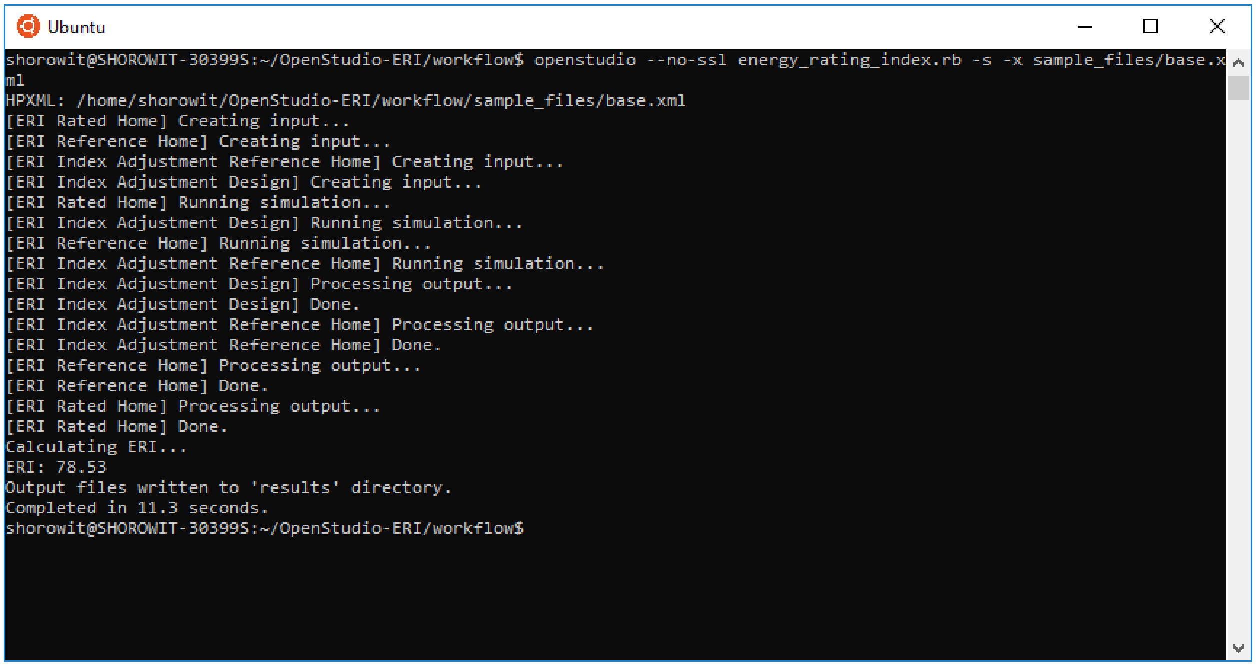
## 3.2 Running

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

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.

CHAPTER 4

# 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`.

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 `WeatherStation/WMO` must be one of the acceptable TMY3 WMO station numbers found in the weather/data.csv file.

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 *.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.

### 4.2.5 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, 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 depth (`UnderSlabInsulationWidth`) or can span the entire slab (`UnderSlabInsulationSpansEntireSlab`).

For foundation types without walls, the `DepthBelowGrade` field must be provided. For foundation types with walls, the slab's position relative to grade is determined by the `FoundationWall/DepthBelowGrade` values.

#### 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` and `FractionCoolLoadServed` must be provided. `CoolingCapacity` must also be provided for all systems other than evaporative coolers.

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

| CoolingSystemType | DistributionSystem | CoolingSystemFuel | AnnualCoolingEfficiency | SensibleHeatFraction |
|---|---|---|---|---|
| central air conditioner | AirDistribution or DSE | electricity | SEER | (optional) |
| room air conditioner | | electricity | EER | (optional) |
| evaporative cooler | AirDistribution or DSE (optional) | electricity | | |

### Heat Pumps

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

| HeatPumpType | DistributionSystem | HeatPumpFuel | AnnualCoolingEfficiency | AnnualHeatingEfficiency | CoolingSensibleHeatFraction | HeatingCapacity17F |
|---|---|---|---|---|---|---|
| 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 | AirDistribution or DSE | electricity | EER | COP | (optional) | |

If the heat pump has integrated 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 (e.g., room air conditioners) are not allowed to be attached to a distribution system.

`AirDistribution` systems are defined by:

- Supply leakage in CFM25 to the outside (`DuctLeakageMeasurement[DuctType='supply']/DuctLeakage/Value`)
- Optional return leakage in CFM25 to the outside (`DuctLeakageMeasurement[DuctType='return']/DuctLeakage/Value`)
- Optional supply ducts (`Ducts[DuctType='supply']`)
- Optional return ducts (`Ducts[DuctType='return']`)

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`, `TestedFlowRate`, `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.

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

| WaterHeaterType | UniformEnergyFactor or EnergyFactor | FuelType | TankVolume | HeatingCapacity | RecoveryEfficiency | RelatedHVACSystem | WaterHeaterInsulation/Jacket/JacketRValue |
|---|---|---|---|---|---|---|---|
| storage water heater | required | <any> | required | <optional> | required if non-electric | | <optional> |
| instantaneous water heater | required | <any> | | | | | |
| heat pump water heater | required | electricity | required | | | | <optional> |
| space-heating boiler with storage tank | | | required | | | required | <optional> |
| space-heating boiler with tankless coil | | | | | | required | |

For combi boiler systems, the `RelatedHVACSystem` must point to a `HeatingSystem` of type "Boiler".

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

### 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`: '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

### 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/eplusout.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.

# CHAPTER 5

# 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 multiple sections with different outputs.

1. **Annual Energy Consumption by Fuel Type**. Current fuel types are: “Electricity”, “Natural Gas”, “Fuel Oil”, “Propane”. It also includes an “Electricity: Net” field that incorporates any renewable generation.

2. **Annual Energy Consumption By Fuel Type and End Use**. Current fuel types are: “Electricity”, “Natural Gas”, “Fuel Oil”, “Propane”. Current end uses are: “Heating”, “Cooling”, “Hot Water”, “Hot Water Recirc Pump”, “Lighting Interior”, “Lighting Garage”, “Lighting Exterior”, “Mech Vent”, “Refrigerator”, “Dishwasher”, “Clothes Washer”, “Clothes Dryer”, “Range/Oven”, “Ceiling Fan”, “Plug Loads”, “PV” (negative value for generation).

3. **Annual Building Loads**. Values are reported for heating, cooling, and hot water. Heating and cooling loads include duct losses. Hot water loads are disaggregated into A) Delivered (i.e., the load associated with the delivered hot water by the water heater), B) Tank Losses, and C) Desuperheater.

4. **Annual Unmet Building Loads**. Values are reported for heating and cooling. 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.

5. **Peak Building Electricity**. Values, in Watts, are reported for the summer and winter seasons. The summer season is defined by the hours of the year when the cooling system is operating, and the winter season is defined by the hours of the year when the heating system is operating.

6. **Peak Building Loads**. Values, in kBtu, are reported for heating and cooling. Heating and cooling peak loads include duct losses.

7. **Annual Component Building Loads**. Component loads represent the estimated contribution of different building components to the annual heating/cooling building loads. The sum of component loads for heating (or cooling) will roughly equal the annual heating (or cooling) building load reported above. Component loads are currently disaggregated as follows:

| Component | Definition |
| --- | --- |
| Roofs | Heat transfer through HPXML `Roof` elements adjacent to conditioned space |
| Ceilings | Heat transfer through HPXML `FrameFloor` elements (inferred to be ceilings) adjacent to conditioned space |
| Walls | Heat transfer through HPXML `Wall` elements adjacent to conditioned space |
| Rim Joists | Heat transfer through HPXML `RimJoist` elements adjacent to conditioned space |
| Foundation Walls | Heat transfer through HPXML `FoundationWall` elements adjacent to conditioned space |
| Doors | Heat transfer through HPXML `Door` elements on surfaces adjacent to conditioned space |
| Windows | Heat transfer through HPXML `Window` elements on surfaces adjacent to conditioned space, including direct/diffuse transmitted solar |
| Skylights | Heat transfer through HPXML `Skylight` elements on surfaces adjacent to conditioned space, including direct/diffuse transmitted solar |
| Floors | Heat transfer through HPXML `FrameFloor` elements (inferred to be floors) adjacent to conditioned space |
| Slabs | Heat transfer through HPXML `Slab` elements adjacent to conditioned space |
| Internal Mass | Heat transfer from additional assumed mass (furniture, interior walls, interior floors between stories) in conditioned space |
| Infiltration | Airflow induced by stack and wind effects |
| Natural Ventilation | Airflow through operable windows |
| Mechanical Ventilation | Airflow (and potentially fan heat gain) from a whole house mechanical ventilation system |
| Ducts | Conduction and leakage losses through supply/return ducts outside conditioned space |
| Internal Gains | Heat gains/losses due to appliances, lighting, plug loads, water heater tank losses, etc. in the conditioned space |
| Setpoint Change | Additional load due to, e.g., recovery from thermostat heating setbacks or cooling setups |

See the example ERIRatedHome.csv.

### 5.1.4 ERI______Home_Hourly.csv

If the `--hourly-output` argument is provided when running the workflow, a CSV file of hourly outputs is written for each of the homes simulated (e.g., `ERIReferenceHome_Hourly.csv` for the Reference home).

The hourly output CSV files currently include:

- Average space temperatures (in deg-F) for each space modeled (e.g., living space, vented attic, garage, unconditioned basement, crawlspace, etc.).
- Whole-building site energy use for each fuel type (in kBtu for fossil fuels and kWh for electricity).

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.

CHAPTER 6

# Testing Framework

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

## 6.1 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

## 6.2 Test Results

Automatic test results in CSV format can be accessed on the CI machine for any job that has completed (e.g., "SUCCESS") under the "Artifacts" tab. Each CI job represents running the complete set of tests for a given GitHub commit. Jobs that have not been completed will not have an "Artifacts" tab with results.

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. In the meantime, 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.

## 6.3 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 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.

Finally the OpenStudio-ERI repo can be cloned, using the latest 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.

Second, the OpenStudio-ERI repo files from the latest release need to be bundled. If you want to slim down the installation package, the minimum required files from the OpenStudio-ERI repo are:

- `measures/*/resources/*.*`
- `measures/*/measure.*`
- `measures/HPXMLtoOpenStudio/hpxml_schema/*.*`
- `weather/*.*`

- workflow/*.rb

CHAPTER 8

# Indices and tables

- genindex
- search