End-Use Savings Shapes

Residential Round 1

Technical Documentation and Measure Applicability Logic

Contents

Section 1 – Baseline Stock Representation

This project was conducted using the ResStock modeling tool (link). The baseline intends to represent the U.S. residential building stock as it existed in 2018. Our baseline modeling went through an extensive improvement and validation process in the End-Use Load Profiles (EULP) project (link). The state of the baseline for this work is very similar to the results of the End-Use Load Profiles project, published in fall 2021, with a few key differences discussed below.

Altogether these updates and changes discussed below had only a minor impact on energy consumption results. The total national energy consumption in this baseline run, for actual meteorological year (AMY) 2018, is 3,440 TWh, compared to 3,370 TWh for the EULP 2201 Release AMY 2018 run (2% increase). The total electricity consumption is 1,550 TWh, compared to 1,480 TWh for EULP 2021 Release (5% increase).

Characteristics and Output Field Differences

Since the end of EULP, we have added several types of new input characteristics, including:

- Household income,
- Household income as percent of federal poverty level (FPL),
- Owner/renter status (tenure),
- City (for dwelling units in cities with more than 15,000 dwelling units)

These are available as data viewer filters and in the metadata files.

Some of the end uses for energy results have been renamed, combined, or otherwise changed. For a complete list of field names and descriptions, please see the data dictionary (link). For this End-Use Savings Shapes (EUSS) dataset release, we are including carbon emissions reduction outputs in addition to energy outputs. Please see Section 3 – Carbon Emissions for details.

Key Model Differences from EULP 2021 Release

HPXML-Based Modeling

In early 2022, ResStock moved to a new model input specification using the HPXML standard schema and the OpenStudio-HPXML workflow (link). This move included new modeling assumptions that led to a small increase in energy consumption, primarily in the cooling end use.

Building Characteristics From U.S. Census' Public Use Microdata Sample (PUMS) 2019

We updated the building type, vintage, vacancy, heating fuel, and number of occupants characteristics distributions using PUMS 2019. These are some of the earlier characteristics in the ResStock conditional distribution stock characterization. The EULP version 1 (2021) results use PUMS 2017 for these characteristics.

Dwelling Unit Counts From the American Community Survey (ACS) 2015-2019

We updated to use ACS 2015-2019 for the total number of dwelling units. This value was from ACS 2012-2016 at the end of EULP. The geographic distribution of the dwelling units is census block based and continues to come from ACS 2012-2016. City boundaries are census block based and from 2020 Census redistricting data.

Partial Space Conditioning for Cooling

We used RECS 2009 data to introduce partial space conditioning for cooling. Room ACs now on average only condition approximately 30% of the floor area, as compared to 100% at the end of EULP.

Baseline Heat Pump Saturations

Since the end of EULP we have separated IECC Climate Zone 2A into two categories for the purpose of heat pump saturation distributions. One category includes the portions of 2A in FL, GA, AL, and MS, and the other includes the portions in TX and LA. The source for heat pump saturation distributions continues to be RECS 2009.

Heat Pump Modeling Improvements

Since the end of the EULP project, and specifically in support of this EUSS effort, we increased our options for heat pump modeling. This includes, in particular, allowing for a greater variety of backup heating options. These changes have relatively little impact on the baseline.

Section 2 – Measure Package Composition and Logic

This first EUSS residential round comprises 10 measure packages, as described below.

First, a Note on Heat Pump Modeling

We model all heat pumps as having supplemental backup heating. In the baseline and in most measure packages, the backup is electric resistance. The exception is Package 5, where existing fuel-fired or electric heating systems are retained as a backup heating sources. In this case, a switchover temperature of 41 °F is used to switch between the heat pump and fuel-fired backup heat in cases where the two share ductwork. In cases with electric resistance backup, or with ductless heat pumps supplemented by existing fuel-fired boilers, the backup heating is active in conjunction with the heat pump whenever the heat pump cannot meet the load.

All centrally-ducted heat pumps in measure packages are sized using ACCA Manual S, which primarily sizes heat pumps based on the cooling load. For higher heating loads, a 15% oversizing allowance applies when the heat pump is single-stage (Measure Packages 3, 5, and 7), and a +1 ton allowance applies if in a cold, dry climate. A 30% oversizing allowance applies to variable-speed heat pumps (Measure Packages 4, 8, 9, and 10).

All ductless heat pumps in measure packages are sized to the larger of the calculated cooling and heating loads for the dwelling unit.

Measure Package 1: Basic Enclosure Package

Summary

- Attic floor insulation up to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation
- General air sealing: 30% total reduction in ACH_{50} for dwelling units with greater than 10 ACH_{50}
- Duct sealing to 10% leakage, R-8 insulation
- Drill-and-fill insulation (R-13) for dwelling units with no insulation and wood stud walls

Technical Description

- Attic floor insulation
    - Applies only to dwelling units with vented attics
    - Value: R-30
        - Applies to IECC CZ 1A
        - Applies to dwelling units with R-13 or less insulation
    - Value: R-49
        - Applies to IECC CZ 2A, 2B, 3A, 3B, 3C
        - Applies to dwelling units with R-30 or less insulation
    - Value: R-60

        - Applies to IECC CZ 4A, 4B, 4C, 5A, 5B, 6A, 6B, 7A, 7B
        - Applies to dwelling units with R-38 or less insulation
- Air leakage reduction
    - Value: 30% whole-home reduction in ACH_{50}
        - Applies to all dwelling units with 15 ACH_{50} or higher infiltration
- Duct sealing
    - Value: 10% Leakage, R-8
        - Applies to all dwelling units with leakier and/or less insulated ducts located in unconditioned space
- Drill-and-fill wall insulation
    - Value: R-13 insulation with wood stud walls
        - Applies to dwelling units with uninsulated wood stud walls

Measure Package 2: Enhanced Enclosure Package

Summary

- Everything in Package 1
- Add R-10 interior insulation to foundation walls and rim joists in conditioned basements and crawlspaces; seal crawlspace vents
- Insulate finished attics and cathedral ceilings to R-30

Technical Description

- Foundation wall insulation and rim joist insulation
    - Value: R-10 interior insulation for foundation walls
    - Value: R-10 exterior insulation for rim joists
        - Applies only to dwelling units with unvented crawlspaces, vented crawlspaces,[1] or heated basements
        - Applies only to dwelling units without foundation wall insulation
- Seal vented crawlspaces
    - Value: unvented crawlspaces, replace vented crawlspaces
        - Applies to single-family detached (SFD), single-family attached (SFA), and bottom-floor multifamily (MF) dwelling units
- Insulate finished attics and cathedral ceilings
    - Value: R-30 roof assembly insulation
        - Applies to SFD, SFA, and top-level MF dwelling units
        - Applies to dwelling units with roof insulation of R-13 or less
        - Applies to dwelling units with finished attics or cathedral ceilings

Measure Package 3: Heat Pumps, Min-Efficiency, Electric Backup

Summary

[1] Unvented crawlspaces are considered conditioned. Vented crawlspaces are sealed to become unvented crawlspaces as part of the same measure package and so are included.

- Centrally-ducted heat pump, SEER 15, 9 HSPF, for dwelling units with ducts, sized with ACCA Manual S
- Ductless minisplit heat pump, SEER 15, 9 HSPF, for dwelling units without ducts, sized to max load

Technical Description

- Centrally -ducted heat pump, SEER 15, 9 HSPF, for dwelling units with ducts, sized with ACCA Manual S
- Ductless minisplit heat pump, SEER 15, 9 HSPF, for dwelling units without ducts, sized to max load

- Centrally-ducted heat pump SEER 15, 9 HSPF
    - Apply to dwelling units with ducts and:
        - No heat pump, or
        - A less-efficient heat pump (SEERs 10, 13, 15; HSPFs 6.2, 7.7, 8.5)
    - Sized to ACCA Manual S
    - Backup heat provided by electric resistance, active when the heat pump can't meet the load
- Ductless mini-split SEER 15, 9 HSPF
    - Apply to dwelling units without ducts and:
        - No heat pump, or
        - A less-efficient heat pump (MSHP SEER 14.5, 8.2 HSPF)
    - Sized to max load
    - Backup heat provided by electric resistance, active when the heat pump can't meet the load

Measure Package 4: Heat Pumps, High-Efficiency, Electric Backup

Summary

- Centrally ducted variable speed heat pump (ducted minisplit) SEER 24, 13 HSPF, for dwelling units with ducts, sized with ACCA Manual S
- Ductless variable speed minisplit SEER 29.3, 14 HSPF, for dwelling units without ducts, sized to max load

Technical Description

- Centrally ducted heat pump, variable-speed mini-split, SEER 24, 13 HSPF
    - Apply to dwelling units with ducts and:
        - No heat pump *or*
        - A less efficient heat pump (SEERs < 24; HSPFs < 13)
    - Sized to ACCA Manual S
    - Backup heat provided by electric resistance, active when the heat pump can't meet the load
- Ductless variable-speed mini-split heat pump SEER 29.3 14 HSPF

    - Apply to dwelling units without ducts and:
        - No heat pump or a less-efficient heat pump (MSHP SEER 14.5, 8.2 HSPF or MSHP SEER 29.3, 14 HSPF not sized to max load)
    - Sized to max load
    - Backup heat provided by electric resistance, active when the heat pump can't meet the load

Measure Package 5: Heat Pumps, Min-Efficiency, Existing Heating as Backup

Summary

- Centrally ducted single-speed heat pump, SEER 15, 9 HSPF for all dwelling units with ducts, sized with ACCA Manual S
- Ductless single-speed mini-split SEER 15, 9 HSPF for all dwelling units without ducts, sized to max load
- Existing heating system retained as backup if non-electric fueled or if it is electric fueled in a dwelling unit with no ducts
- Electric resistance backup for dwelling units with ducted electric heating in baseline

Technical Description

- Centrally ducted single-speed heat pump SEER 15, 9 HSPF, with electric resistance backup
    - Applies to dwelling units with ducts and:
        - No heat pump *or* a less-efficient heat pump
        - With existing electric heating
    - Backup heat provided by electric resistance, active when the heat pump can't meet the load
    - Sized to ACCA Manual S
    - Example configurations where this would apply: Central AC + electric furnace; No AC + electric furnace; existing heat pump; Central AC + electric baseboard heating
- Centrally ducted single-speed heat pump SEER 15, 9 HSPF, with existing heating as independent backup
    - Applies to dwelling units with ducts and:
        - No heat pump *or* a less-efficient heat pump
        - With existing non-ducted, non-electric heating
    - Existing heating retained as backup, active when the heat pump can't meet the load
    - Sized to ACCA Manual S
    - Example configurations where this would apply: Central AC + propane boiler; Central AC + natural gas wall/floor furnace
- Centrally ducted single-speed heat pump SEER 15, 9 HSPF, with existing heating sharing ducts
    - Applies to dwelling units with ducts and:
        - No heat pump *or* a less-efficient heat pump
        - With existing ducted, non-electric heating
    - Existing heating retained as backup, active below switchover temperature. Heat pump provides heating above switchover temperature of 41 °F .
    - Sized to ACCA Manual S

    - Example configurations where this would apply: Central AC + fuel oil furnace; Room AC + natural gas furnace
- Ductless single-speed mini-split SEER 15, 9 HSPF, with existing heating as independent backup
    - Apply to dwelling units without ducts and:
        - No heat pump *or* a less-efficient heat pump
    - Sized to max load
    - Existing heating retained as backup, active when the heat pump can't meet the load
    - Example configurations where this would apply: Room AC + electric baseboard, No AC + natural gas boiler

Measure Package 6: Heat Pump Water Heaters

Summary

- Heat pump water heater with Uniform Energy Factor (UEF) 3.35-3.45 for all dwelling units with an existing water heater other than an electric tankless water heater

Technical Description

- 50 gallon, 3.45 UEF heat pump
    - For dwelling units with 1-3 bedrooms and an existing water heater other than an electric tankless water heater
- 66 gallon, 3.35 UEF
    - For dwelling units with 4 bedrooms and an existing water heater other than an electric tankless water heater
- 80, 3.45 UEF
    - For dwelling units with more than 4 bedrooms and an existing water heater other than an electric tankless water heater

Measure Package 7: Whole-Home Electrification, Min Efficiency

Summary

- No enclosure measures
- No change to existing electric loads
- Minimum-efficiency heat pump (Measure Package 3) for dwelling units with non-electric heating
- Heat pump water heater for dwelling units that currently have non-electric water heating (same logic as Measure Package 6, with the additional requirement of non-electric water heating fuel)
- Electric resistance dryer for dwelling units that currently have non-electric dryers
- Electric range for dwelling units that currently have non-electric range

Measure Package 8: Whole-Home Electrification, High Efficiency

Summary

- No enclosure measures

- High-efficiency heat pump (Measure Package 4) for all dwelling units with non-electric heating or less-efficient electric heating
- Heat pump water heater for all dwelling units with non-electric heating or less-efficient electric water heating
- Ventless heat pump dryer (CEF=5.2) for all dwelling units with non-electric dryers or less-efficient electric dryers
- Electric oven and induction range for all dwelling units

Measure Package 9: Whole-Home Electrification, High Efficiency + Basic Enclosure Package

Summary

- Packages 1 & 8

Measure Package 10: Whole-Home Electrification, High Efficiency + Enhanced Enclosure Package

Summary

- Packages 2 & 8

Section 3 – Carbon Emissions

We included four sets of carbon emissions impact results in this data release. Carbon emissions impact results are not available in the data viewer's graphical user interface or associated custom timeseries downloads, but are available in the metadata and annual results files, individual building timeseries results, and pre-aggregated timeseries results. Custom aggregations at the annual level can be made in Excel.

Emissions Associated With Changes in Non-Electric On-Site Fuel Consumption

We used the following values for non-electric on-site fuel consumption.

- Natural gas: 147.3 lb/mmbtu (228.0 kg/MWh)
- Propane: 177.8 lb/mmbtu (182.3 kg/MWh)
- Fuel oil: 195.9 lb/mmbtu (303.2 kg/MWh)

These values are from *Table 7.1.2(1) National Average Emissions Factors for Household Fuels* from draft *ANSI/RESNET/ICCC 301 Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index* (link). They include both the combustion and pre-combustion (e.g., methane leakage for natural gas) CO_2e emissions.

Emissions Associated With Changes in Electricity Consumption

We selected four different sets of long-run marginal CO_2e emissions factors from NREL's Cambium database. We recommend using multiple scenarios to understand the range of potential emissions outcomes.

NREL Standard Scenario	Start Year	Levelization Period (3% discount rate)
MidCase	2025	15 years
LowRECost	2025	15 years
95% Decarbonization by 2035	2025	15 years
LowRECost	2025	25 years

The last of these is the set of long-run marginal emissions that has been selected for use by RESNET.

We used the month-hour timeseries version of each of these factors, which captures daily and seasonal variation without concerns about weather year correspondence. We applied these factors at the Generation Emission Assessment Region geographic level. See the Cambium documentation for additional information.

Carbon Emissions Applicability

These calculated carbon emissions impact results are based upon electric long-run marginal emissions rates, based on a consequentialist accounting framework, and are intended only for use in calculating emissions impacts from changes to the building stock. They are not intended for greenhouse gas inventory efforts.

Section 4 – Outputs

We are outputting energy for baseline, post-measure, and savings, calculated using three different sets of weather data: AMY2018, AMY2012, and TMY3.

Outputs are available in a variety of formats:

1. *Individual model characteristics (metadata) and annual results, usable in Excel. These are at the model level and should be multiplied by the sample weight in order to represent the housing stock.
2. *Pre-aggregated timeseries results, usable in Excel. These represent the housing stock.
3. Web data viewer.
    a. Allows in-browser viewing, filtering, and exporting of housing stock results.
    b. Downloadable custom aggregated 15-minute timeseries data for any combination of filters.
    c. We strongly encourage using the individual model characteristics (metadata) and annual results files to check the sample sizes of filtered data sets. Sample sizes that include 1,000 models or more (representing 240,000 dwelling units or more) are strongest.
4. *Individual model input files and results.

* Note: emissions results, PV, and totals including PV (e.g., net consumption) are only available in the starred formats.

Section 5 – Important Notes

RECS 2009

While we have used more up-to-date sources where available, several of our input dwelling unit characteristic distributions continue to rely on RECS 2009 data due to RECS 2020 microdata not yet being fully available and lack of resolution with the RECS 2015 data. We will be updating to RECS 2020 data over the next year.

Other Fuels

We do not represent on-site use of fuels other than electricity, natural gas, propane, and fuel oil (e.g., wood, coal). We do include appliances using these other fuels in our housing stock characterization, but the fuel consumption is outside of our scope and not represented.

We are aware that clothes washers and clothes dryers in dwelling units with water heaters that use non-modeled fuels currently show no energy consumption. This impacts 0.2% of all clothes washers and dryers in our baseline AMY2018 results.

Heat Pump Water Heater Interaction Factor

Because we model all dwelling unit living space as a single thermal zone, we currently use an *interaction factor* of 1.0 for heat pump water heaters. The interaction factor is the degree to which the cooling effect of the heat pump water heater is sensed by the heating system thermostat. Several studies have shown a lower value may be more correct, indicating that not all of the heat removed from nominally conditioned space by a heat pump water heater during the heating season is subsequently delivered by the heating system. We may use a lower interaction factor in the future.

Heat Pump Backup Heating

Heat pump backup heating is reported as four end uses (one for each fuel type) that are separate from the four primary heating end uses. Total heating load should be considered to be the total of heat pump backup heating and primary heating end uses.

The way that our models are currently set up, heating systems sizes are re-calculated when they are re-designated as backup heating. This is relevant for Measure Package 5, where existing heating systems are re-designated as heat pump backup heating systems. However, when the sizing changes, the energy consumption is largely unaffected by the sizing change – in the worst case (with 200% expected sizing and extremely leaky ducts), we saw a 7% decrease in heating energy consumption. In most cases the sizing change was minimal. The median sizing increase across all backup systems is 0% and the average sizing increase is 3%.