# A Data-Driven Housing Stock Analysis of Southeast Pennsylvania

*Elaina Present, National Renewable Energy Laboratory, Golden, CO*
*Liz Compitello, Delaware Valley Regional Planning Commission, Philadelphia, PA*
*Lauren Pawlowski, Delaware Valley Regional Planning Commission, Philadelphia, PA*

## ABSTRACT

A four-county area in southeast Pennsylvania is developing a roadmap of strategies to improve the accessibility and delivery of whole-home energy improvement programs for low-income homeowners. A team of researchers and subject matter experts is conducting a housing stock analysis of the area to inform the development of the roadmap, presented here as an in-progress case study.

ResStock™ datasets, developed by the National Renewable Energy Laboratory and funded by the U.S. Department of Energy, form the foundation of this housing stock analysis, which also uses location-specific energy utility rates and retrofit measure first costs developed specific to the project. The analysis includes modeled results related to the housing stock of the study area: its associated modeled characteristics, site energy consumption, emissions, energy utility bills, and energy affordability, as well as the modeled impacts of seven retrofit measure packages on these same metrics plus first cost and net present value. Although the analysis and results are specific to one geographic area, the data sources, tools, and methodologies used are applicable throughout the United States and can contribute to housing stock analysis and building retrofit work in other areas of the country.

### Introduction

This paper presents an in-progress case study of a housing stock analysis conducted using ResStock to help inform and scale similar efforts across the U.S. The project-specific goals, methodology, and results to date are presented and discussed alongside how assumptions and preliminary results were developed, reviewed, discussed, and refined with project partners.

#### The E2C Delaware Valley Project

The Delaware Valley Regional Planning Commission (DVRPC) is the federally designated Metropolitan Planning Organization for the greater Philadelphia region. DVRPC was the community team selected in 2023 for a U.S. Department of Energy (DOE) Energy to Communities (E2C) in-depth partnership (NREL 2025). Through this partnership, DVRPC is working with DOE national laboratories and regional project team members to develop a plan to establish the Southeast PA Regional Energy Center that will help sustain existing and develop new energy-focused programs at DVRPC. A primary focus of the research is to identify opportunities to improve the accessibility and delivery of whole-home energy improvement programs for low-income homeowners in single-family houses in southeast Pennsylvania, similar to the Philadelphia Energy Authority's Built to Last Program (Philadelphia Energy Authority 2025). The National Renewable Energy Laboratory (NREL) is the lead national laboratory, and Lawrence Berkeley National Laboratory and Oak Ridge National Laboratory are providing technical support to the project team. DVRPC's regional partners include local governments, the primary investor-owned utility serving this geography (PECO), non-profits, and community-based organizations, including the ecosystem of service providers in southeast Pennsylvania that support low-income homeowners with whole-home energy improvement services, such as home repair, weatherization, energy efficiency, equipment upgrade, and on-site renewable energy projects.

DVRPC developed a detailed work plan for this E2C In-Depth Partnership project which outlines the research and analysis to inform an implementation plan. Elements of the work plan include a regional analysis of the housing stock in southeast Pennsylvania using ResStock, as detailed in this paper. The ResStock analysis will help the project team assess opportunities and challenges in program design and delivery and will serve as an input to other elements of the work plan including stakeholder and community engagement, analysis of the local workforce, and an evaluation of gaps and opportunities for funding whole-home residential energy improvements for low-income residents.

### ResStock

ResStock is a building stock energy model developed by NREL and funded by DOE that represents the U.S. housing stock circa 2018 (Reyna et al. 2025). ResStock datasets provide credible information about the housing stock and its energy consumption in the contiguous United States as it is, as well as its technical potential with retrofit measures applied.

ResStock datasets include hundreds of thousands of housing unit models that represent the variety of the U.S. housing stock as accurately as possible using the best available data. The housing unit models' site energy consumption and associated emissions and energy utility bills are modeled using OpenStudio® and EnergyPlus™. The resulting ResStock datasets can be used to analyze specific segments of housing, such as a specific geography, housing type, or vintage. 4,097 of the models from ResStock 2024 Release 2 (White et al. 2024) are in the four-county study area and form the basis for this analysis.

ResStock models the application of retrofit measure packages to the housing stock using an "if-then" logic-based approach. For example, a measure package could be specified replacing all incandescent lighting with high-efficacy LEDs, with no changes to any other lighting. Any dwelling unit models with any characteristics change under the specified logic have their energy consumption re-simulated. ResStock models measures that are possible, regardless of whether they are a good idea for a particular house and results must be evaluated together with information such as costs and alternative opportunities.

The result of ResStock retrofit measure analysis is the overnight technical potential of a specific retrofit measure package, including the modeled impacts on site energy consumption, energy utility bills, and emissions. These results can be used directly or as inputs to other analyses such as adoption modeling or technology turnover studies. The overnight technical potential is a theoretical maximum impact, without consideration of economics, workforce capacity, or other practical aspects.

This housing analysis uses ResStock results together with location-specific utility rates and retrofit measure first costs to characterize the housing stock, current site energy consumption, emissions, energy utility bills, and energy affordability of the study area, as well as the impacts of seven retrofit measure packages on these same metrics plus first cost and net present value. This information is intended to inform the broader E2C Delaware Valley project including program design and delivery and identification of gaps and opportunities for whole-home residential energy improvements for low-income residents.

## Methodology

### Data, Inputs, and Equations

**Geographic resolution.** The study area for DVRPC's project includes the portions of the four Philadelphia collar counties (Bucks, Chester, Delaware, and Montgomery) that are within PECO electric service territory. The project's NREL housing stock analysis team found that the portions of the counties that were outside PECO's electric service territory were not easily separated because they did not align with the sub-county geographic resolution options in ResStock datasets (i.e., public use microdata area (PUMA) from the U.S. Census) and that they did not disproportionately impact results because they were generally

areas lower in population density. Based on these observations and limitations, the project team agreed to use the full four counties as the study area for the housing stock analysis.

**Weather data year.** The analysis uses the Actual Meteorological Year (AMY) 2018 weather data results in the ResStock 2024 Release 2 dataset. Using the AMY2018 results instead of the Typical Meteorological Year 3 (TMY3) results ensures that the weather is aligned across geographies[1] and allows comparisons between the results of this analysis and other 2018 data from utilities or other sources.

**Site energy consumption.** Site energy consumption results are from the AMY2018 results in the ResStock 2024 Release 2 dataset directly for the four counties in the study area.

**Emissions.** The ResStock 2024 Release 2 dataset includes four sets of emissions results. The NREL and DVRPC project teams selected one of these sets of results for inclusion in this analysis: the Cambium 2022 MidCase 15-year scenario[2], which uses the emissions factors shown in Table A.

**Utility rates.** The NREL team identified current utility rates (as of Spring 2025) from Pennsylvania Public Utilities Commission (PUC) Rate Comparison reports (PA PUC 2025) for electricity and natural gas, and from U.S. Energy Information Administration (EIA) state-level data (U.S. EIA 2025) for fuel oil and propane. The annual energy utility bills were calculated using these rates, shown in Table A, together with the site energy consumption from ResStock. The savings were calculated as the difference between the baseline energy utility bills and the bills with a retrofit measure applied.

Table A. Emissions factors and utility rates used in this housing stock analysis.

| End-Use Fuel | Emissions Factor | Utility Rate |
|---|---|---|
| Electricity | A time-varying factor averaging out to approximately 340 kg $CO_2e$/MWh | $11.25/month + $0.1978/kWh |
| Natural Gas | 147.3 lb $CO_2e$ /MMBtu (228.5 kg $CO_2e$ /MWh) | $15.70/month + $0.03973/kWh ($15.70/month + $1.2085/Ccf) |
| Fuel Oil | 195.9 lb $CO_2e$ /MMBtu (303.9 kg $CO_2e$ /MWh) | $0.08265/kWh ($3.3669/gallon) |
| Propane | 177.8 lb $CO_2e$ /MMBtu (275.8 kg $CO_2e$ /MWh) | $0.1101/kWh ($2.9545/gallon) |

**Energy affordability ratio.** The NREL team calculated the energy affordability ratio for each occupied ResStock housing unit model and measure package combination as the ratio of the household energy utility bill, calculated using the analysis-specific utility rates, to the household's modeled income from ResStock. Higher energy affordability ratios are therefore associated with higher utility bills or lower household incomes. Using income circa 2018 with utility rates from 2025 for this calculation means the

[1] See Section 2.4.1 of (Wilson et al. 2022)

[2] For electricity, this uses a long-run marginal emissions factor for the RFCEc region from Cambium 2022 (Gagnon, Cowiestoll, and Schwarz 2023)**,** developed using the MidCase NREL Standard Scenario grid future and levelized at 3% over 2025-2040. It is a forward-looking electricity emissions factor, chosen to support both the baseline housing stock analysis and the analysis of retrofit measures applied to this housing stock. It reflects one set of projections for the potential future of the electric grid and its associated emissions factors over the lifetime of implemented measures. For non-electric emissions, it uses the emissions factors from Table 7.1.2(1) of draft PDS-01 of BSR/RESNET/ICCC 301 Addendum B, $CO_2$ Index (BSR/RESNET/ICC 301-2022 2022).

energy affordability ratio results likely indicate energy bills account for a higher portion of income than is actually the case. This inconsistency is a limitation of this work.

**First costs.** An NREL subcontractor, ICF, developed first cost equations specifically for this project, relying primarily on data from RSMeans (Gordian 2025). ICF provided two sets of costs, one for Doylestown, PA, which the NREL team used for Bucks and Montgomery Counties, and one for West Chester, PA, which the team used for Chester and Delaware Counties. The cost data, equations, and information they provided, including their methodology documentation, was made available to the full project team (Taylor et al. 2025).[3] The NREL team used these equations to calculate first costs by providing ResStock-generated inputs to the cost equations, such as the size of the model's attic or water heater.

These costs represent the total first costs of each measure package, reflecting the costs if the measures were implemented before the end of service life of the existing equipment. Additionally, current or potential future incentives, rebates, or tax credits were not considered in the calculation.

**Net present value.** The NPV is calculated for each housing unit model and measure using the modeled first cost and annual energy utility bill savings and an analysis period and discount rate. This analysis uses:

- Analysis period: 15 years, consistent with the measure lifetime used in the emissions calculations.
- Discount rate: 2.5%, calculated as a 5% interest rate minus a 2.5% inflation rate. The interest rate is the rounded midpoint of median 30 year fixed-rate mortgage and median 15 year fixed-rate mortgage in 2022 (Freddie Mac 2025). The inflation rate is the one-year value as of February 2025, accessed through the Federal Reserve and the NREL Annual Technology Baseline (NREL 2023).

The NPV is therefore calculated as

$$\sum_{i=0}^{15\ years} \frac{1}{1.025^i}(cost_i - savings_i)$$

where *cost* is the first cost of the measure package in the initial year and zero thereafter, and *savings* is the annual energy utility bill savings from the measure package each year. No other costs or values were included, such as any changes in maintenance costs.

This calculation and the emissions are both implicitly based on a lifetime of 15 years for all measures – no replacement cost or residual value component has been included in the calculations.

**Measure Packages**

The NREL and DVRPC teams considered two of the more recent ResStock datasets (ResStock 2024 Release 1 and ResStock 2024 Release 2) including discussions of available timescales, weather data used for modeling, and available measure packages, in the context of project goals and priorities. Based on these discussions a set of seven measure packages from the ResStock 2024 Release 2 dataset was selected as a proposal for use in the analysis. This set of packages was presented to the entire project team for review and comment and ultimately selected for the analysis.

The seven measure packages range from basic weatherization to more comprehensive retrofits. They include the following envelope; water heating; heating, ventilation, and air conditioning (HVAC); and appliance measure components, assembled into the measure packages shown in Table B.

**Envelope.** "Light Touch" envelope includes:

- Attic floor insulation increased to IECC-Residential 2021 levels for dwelling units with vented attics and lower-performing insulation

[3] Not published externally as of August 2025.

- General air sealing: 30% total reduction in infiltration for dwelling units with more than 10 air changes per hour at 50 pascals (ACH50)

**Water heating.** Heat pump water heater (HPWH) measure component includes:

- 50 gal HPWH, 3.45 Unified Energy Factor (UEF) for dwelling units with 3 or fewer bedrooms
- 66 gal HPWH, 3.35 UEF for dwelling units with 4 bedrooms
- 80 gal HPWH, 3.45 UEF for dwelling units with 5 or more bedrooms

This measure component applies if the existing water heater uses natural gas, propane, or fuel oil, or is a lower-UEF electric water heater.

**HVAC.** See Table B.

Table B. HVAC measure components included in this analysis from ResStock 2024 Release 2.

| HVAC Measure Component | Performance Specs | Applicability Criteria | Measure for Single-Family Houses with HVAC Ducts | Measure for Single-Family Houses without HVAC Ducts |
|---|---|---|---|---|
| ENERGY STAR heat pump with existing heating as backup | - SEER 16, 9.2 HSPF<br>- Capacity retention of 50% at 5°F<br>- Backup heat provided by the existing heating system when the heat pump cannot meet the load | - Existing heating fuel of natural gas, propane, or fuel oil | - Centrally ducted air-source heat pump<br>- Single-stage<br>- Sized to ACCA Manual S/J | - Mini-split heat pump<br>- Variable speed<br>- Sized to maximum of the heating and cooling design loads<br>- Setpoint offsets removed |
| High-efficiency cold-climate heat pump with electric backup | - SEER 20, 11 HSPF<br>- Capacity retention of 90% at 5°F<br>- Backup heat provided by electric resistance when the heat pump cannot meet the load | - Existing heating fuel of electricity, natural gas, propane, or fuel oil | - Centrally ducted air-source heat pump<br>- Variable speed<br>- Sized to maximum of the heating and cooling design loads<br>- Setpoint offsets removed | - Mini-split heat pump<br>- Variable speed<br>- Sized to maximum of the heating and cooling design loads<br>- Setpoint offsets removed |
| Ultra-high-efficiency cold-climate heat pump with electric backup | - SEER 24, 13 HSPF<br>- Capacity retention of 90% at 5°F<br>- Backup heat provided by electric resistance when the heat pump cannot meet the load | - Existing heating fuel of electricity, natural gas, propane, or fuel oil | - Centrally ducted air-source heat pump<br>- Variable speed<br>- Sized to maximum of the heating and cooling design loads<br>- Setpoint offsets removed | - Mini-split heat pump<br>- Variable speed<br>- Sized to maximum of the heating and cooling design loads<br>- Setpoint offsets removed |

**Appliances.** Four independent measure package components:

- Electric dryer measure component, Combined Energy Factor (CEF) 3.93, for dwelling units with dryers that use natural gas or propane
- Electric induction cooktop and electric oven measure component for dwelling units with ranges that use natural gas or propane
- Electric pool heater measure component for dwelling units with natural gas pool heaters
- Electric spa heater measure component for dwelling units with natural gas spa heaters

**Measure Packages.** Table C contains the seven measure packages included in this analysis and the measure components described above that they consist of.

Table C. The seven measure packages included in this analysis.

| Measure Package Name | HVAC Component(s) | Water Heating Component(s) | Appliance Component(s) | Envelope Component(s) | Applicability Notes | Applicability in Study Area's Single-Family Houses | Measure Package # in ResStock 2024 Rel. 2 |
|---|---|---|---|---|---|---|---|
| Envelope Only – Light Touch Envelope | None | None | None | Light-touch envelope (attic insulation, air sealing) | Applicability of attic insulation & air sealing evaluated individually | 89% | 16 |
| ENERGY STAR Heat Pump with Existing System as Backup | ENERGY STAR heat pump with existing heating as backup | None | None | None | If HVAC applies, the applicability of other components is evaluated individually. If HVAC does not apply, nothing applies. | 75% | 4 |
| High-Efficiency Cold-Climate Heat Pump with Elec. Backup | High-efficiency cold-climate heat pump with electric backup | None | None | None | | 98% | 2 |
| ENERGY STAR Heat Pump with Existing System as Backup + Light Touch Envelope | ENERGY STAR heat pump with existing heating as backup | None | None | Light-touch envelope (attic insulation, air sealing) | | 75% | 9 |
| High-Efficiency Cold-Climate Heat Pump with Elec. Backup + Light Touch Envelope | High-efficiency cold-climate heat pump with electric backup | None | None | Light-touch envelope (attic insulation, air sealing) | | 98% | 7 |
| High-Efficiency Cold-Climate Heat Pump with Elec. Backup + Light Touch Envelope + HPWH + Electric Appliances | High-efficiency cold-climate heat pump with electric backup | Heat pump water heater | Electric dryer<br>Electric cooktop & oven<br>Electric pool heater<br>Electric spa heater | Light-touch envelope (attic insulation, air sealing) | | 98% | 12 |
| Ultra-High-Efficiency Cold-Climate Heat Pump with Elec. Backup + Light Touch Envelope + HPWH + Electric Appliances | Ultra-high-efficiency cold-climate heat pump with electric backup | Heat pump water heater | Electric dryer<br>Electric cooktop & oven<br>Electric pool heater<br>Electric spa heater | Light-touch envelope (attic insulation, air sealing) | | 98% | 13 |

## Data Processing

The NREL team downloaded the ResStock 2024 Release 2 dataset results for Pennsylvania, AMY2018, for the baseline (up00) and the upgrades listed in Table C from the Open Energy Data Initiative (OEDI). The team wrote a custom data processing class in Python and an associated Python notebook to extract only the columns and samples needed, calculate the project-specific energy utility bills, first costs, energy affordability ratio, and NPV, and convert results fields to long format. Housing characteristics remained in wide format, and a few key results fields were output in wide format as well as long. Three files of processed results were generated: one for the baseline housing stock for the entire state of Pennsylvania, one for the baseline housing stock for the four-county study area, and one for the baseline and all seven measure packages for the study area. This third file was over 6.4 GB in size.

Each file was then loaded into Tableau Desktop where limited additional aggregation of ResStock fields was completed (e.g., grouping the vintages into three categories) and all figures were made. Tableau handled the 6.4 GB file, but a larger study area or larger set of upgrades may have required a different data structure, such as constructing two separate files, one with building characteristics by ID in wide format, and one with all results by ID in long format, and then associating the two within Tableau.

The figures were exported from Tableau and provided to the project team in presentation decks, one for the baseline analysis and one for the retrofit measures analysis. These presentation decks included methodological information, light interpretation information for each figure, and key overall takeaways from each step of the analysis, together with the figures themselves.

## Housing Types Included

The project was originally scoped only for single-family houses. In keeping with this framework and the larger project priorities, most results were generated and presented for single-family houses only, including both detached and attached. These represent 77% of the housing units (21% attached, 56% detached) and 3,153 of the 4,097 of the models in the four-county study area in ResStock Dataset 2024 Release 2. Select headline results such as total site energy consumption were additionally presented for all five housing types included in the ResStock dataset: single-family detached, single-family attached, multifamily in a building with 2-4 units, multifamily in a building with 5+ units, and mobile homes.

## Collaboration

This analysis benefited from a wide range of specialties, knowledge, and experience. The team that led the housing stock analysis has extensive experience with ResStock results and building science. The E2C DVRPC community team knows the relevant regional stakeholders and the types of information that are most helpful for local decision-making. Other sub-teams on the E2C DVRPC project provided key inputs such as energy utility rates and first cost equations. The community team also includes local technical experts on specific topics who were able to provide targeted feedback on topics such as relevant measure packages and utility rates.

Every decision made in this project came about through discussion and sometimes debate between relevant teams which would not have been possible in a smaller project or a tighter schedule. These opportunities for collaboration were deliberate and regular. The NREL portion of the E2C DV team met weekly with itself, and a subset met weekly with DVRPC with additional members brought in as needed. Monthly meetings were also held with the entire project team.

## Results

The housing stock analysis team created presentation decks for each of the baseline and retrofit measure analyses, extracted the data as individual data tables, and shared both the presentation slides and the data tables with the entire project team.

Select headline figures from each part of the analysis are included in this paper.

### Baseline Results

From the baseline housing results, the team provided 74 unique figures in the following categories:

- Study Area in Context, comparing the study area to the state of Pennsylvania
- Housing Stock Overview
- Households Overview, with information such as income and owner vs renter status of occupants
- Modeled Energy Consumption, Emissions, and Utility Bills Overview
- Modeled Energy Affordability Overview
- Envelope, showing envelope characteristics of the housing stock[4]
- HVAC, showing HVAC-related characteristics of the housing stock and HVAC energy consumption
- Water Heating, showing water heating-related characteristics of the housing stock and water heating energy consumption
- Appliances, showing appliance-related characteristics of the housing stock and appliance energy consumption
- Miscellaneous, showing miscellaneous energy consumption such as plug loads

Versions of several of the headline figures from these results are shown in this section.

Figure 1 shows the number of housing units in each county, which ranges from 204,000 in Chester to 342,000 in Montgomery, and the distribution of housing units by housing type.

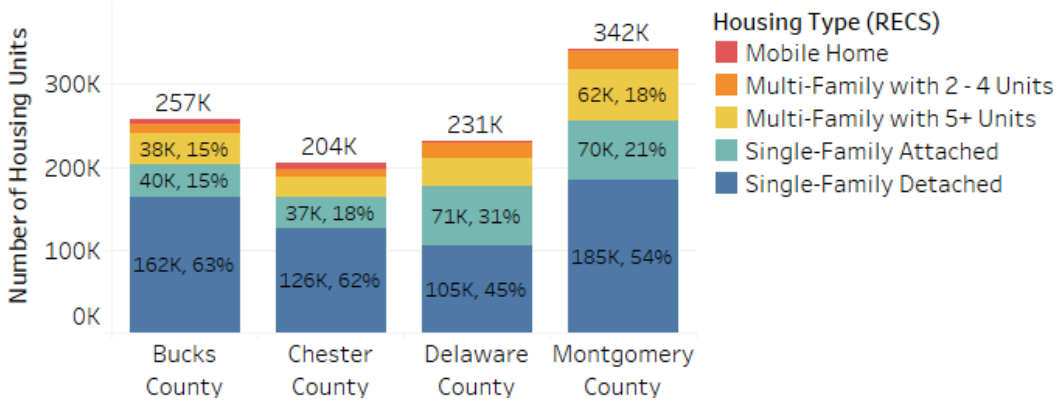


Figure 1. Number and percentage of housing units in each county in the study area, by housing type, using Residential Energy Consumption Survey (RECS) housing type definitions

Figure 2 shows the number of single-family houses in each county by vintage, heating fuel, and income. Vintage is an important characteristic in part because houses built before 1980 were generally not subject to energy codes at the time of construction (Halverson, Shui, and Evans 2009). Of the four counties, the highest portion of houses with fuel oil heating and with electric heating is in Bucks, with propane heating is in Chester, and with natural gas heating is in Montgomery.

[4] Due to ResStock data limitations, no envelope characteristics or appliance saturations were shown by county.

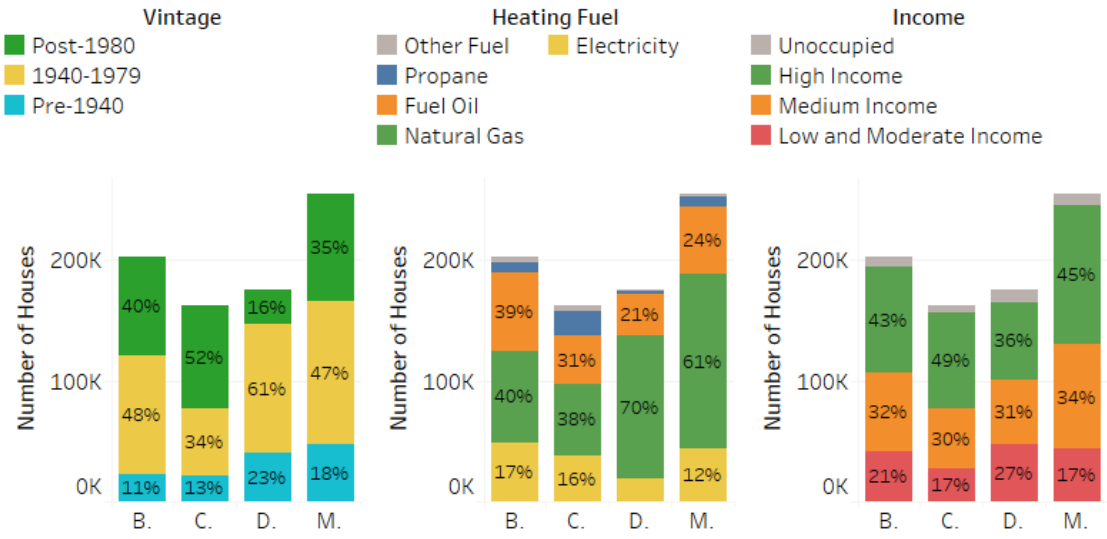


Figure 2. Number and percentage of modeled single-family houses in each county in the study area by vintage, heating fuel, and income. "Low and moderate income" represents Area Median Income (AMI) under 80%, "medium" represents 80%-150% AMI, and "high" represents over 150% AMI. The four counties in the study area are represented by their initial letters: B for Bucks, C for Chester, D for Delaware, and M for Montgomery.

Figure 3 shows the average annual site energy consumption, emissions, energy utility bills, and by county for single-family homes, as well as the number of single-family houses by energy affordability ratio. The counties that use more natural gas relative to other fuels show lower average energy utility bills. That they do not also show the lowest portion of households with high and severe energy affordability ratio is likely due to differences in average household income between the counties.

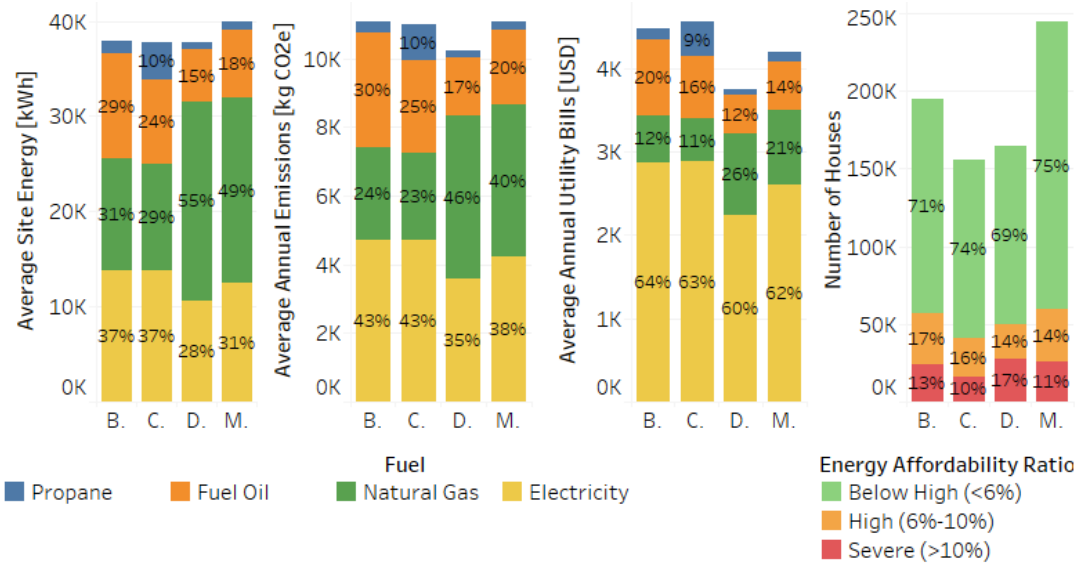


Figure 3. The first three subfigures show average modeled annual site energy consumption, emissions, and energy utility bills for single-family houses in each county, together with the percentage of each associated with each of the four modeled fuels. The fourth subfigure shows the number and percentage of occupied single-family houses by modeled energy affordability ratio. These modeling results reflect the inputs used in the modeling, including higher per-site-kWh costs for electricity and lower per-site-kWh costs for natural gas.

Table D shows the average per-house baseline results for the most common single-family housing categories in the study area as defined by income, vintage, occupancy, and heating fuel.

Table D. Average modeled baseline annual site energy consumption, emissions, energy utility bills, and energy affordability in the three largest housing categories for each income group in the study area. NG is natural gas.

| Income | Vintage | Occu-pancy | Heating Fuel | Houses [qty] | Avg. Site Energy Consum-ption [kWh/yr] | Avg. Emis-sions [kg $CO_2e$/ yr] | Avg. Energy Utility Bill [USD/ yr] | Avg. Energy Afford-ability Ratio |
|---|---|---|---|---|---|---|---|---|
| Low and Moderate | 1940-79 | Owner | NG | 37k | 41k | 10k | $3.3k | 14% |
| Low and Moderate | 1940-79 | Owner | Fuel Oil | 24k | 42k | 13k | $4.8k | 21% |
| Low and Moderate | Pre-1940 | Owner | NG | 17k | 42k | 11k | $3.2k | 13% |
| Medium | 1940-79 | Owner | NG | 51k | 45k | 11k | $3.6k | 4% |
| Medium | 1940-79 | Owner | Fuel Oil | 43k | 44k | 14k | $5.1k | 6% |
| Medium | Post-1980 | Owner | NG | 34k | 34k | 9k | $3.2k | 4% |
| High | Post-1980 | Owner | NG | 85k | 40k | 10k | $3.6k | 2% |
| High | 1940-79 | Owner | NG | 61k | 52k | 13k | $4.0k | 2% |
| High | 1940-79 | Owner | Fuel Oil | 50k | 49k | 15k | $5.6k | 3% |

Figure 4 shows modeled total annual countywide site energy consumption in single-family houses by end use. Despite noticeable differences between counties in how much of each fuel is used, each county uses each fuel for similar purposes when used: natural gas, fuel oil, and propane primarily for HVAC with some water heating and only small amounts of other uses, and electricity about half for HVAC and water heating and half for other purposes such as miscellaneous (mostly plug loads), appliances, and lighting. Note that site electricity consumption for HVAC includes all cooling (i.e., air conditioning), fans, and pumps, and some heating. Natural gas, fuel oil, and propane HVAC energy consumption are exclusively for heating.

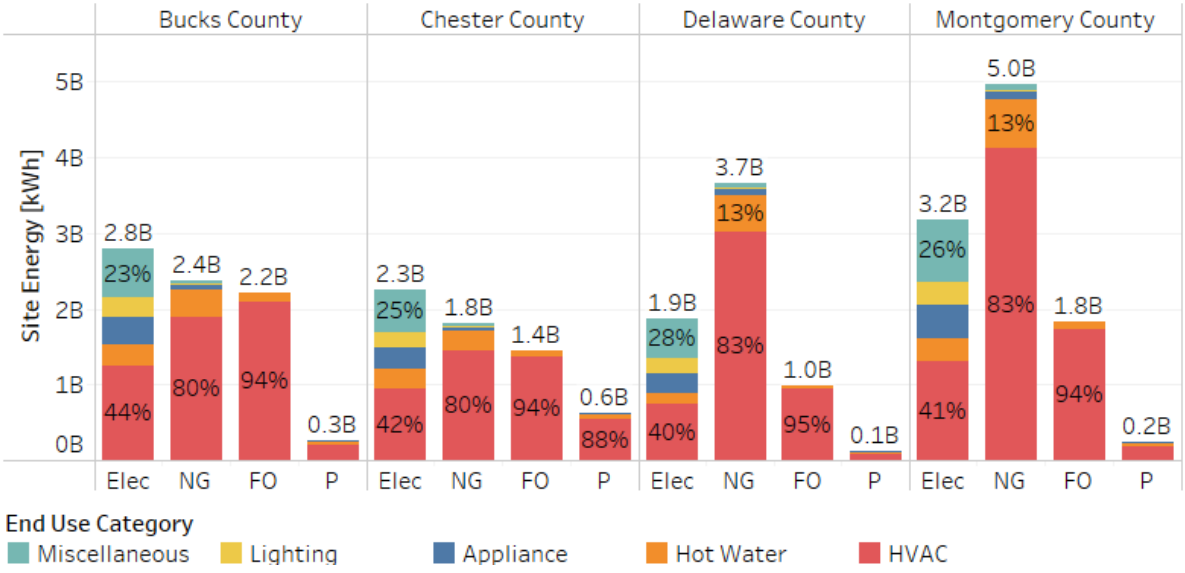


Figure 4. Modeled total site energy consumption of each fuel and percentage used for each end use in each county. Elec is electricity, NG is natural gas, FO is fuel oil, P is propane.

**Retrofit Measure Results**

From the retrofit measure analysis results, the team provided 42 unique figures in these categories:

- Applicability of measure packages
- Impacts of retrofit measures on site energy consumption, emissions, and energy utility bills
- Energy utility bill changes and energy affordability
- First cost and net present value
- End-use energy consumption

Versions of several of the headline figures from these results are shown in this section. Note that the population of houses included varies between figures. Figures 5 and 6 include all single-family houses in the study area, regardless of whether individual measure packages apply. Figures 7, 8, and 9 include only single-family houses where the respective measure package is applicable. Figure 8 also further removes unoccupied houses. The portion of single-family houses in the study area where each of the measure packages is applicable is shown in Table C. Note also that, atypically, all site energy consumption is shown in units of kWh, including site energy consumption of natural gas, propane, and fuel oil.

Figure 5 shows the per-house average modeled site energy consumption by fuel and measure package. All packages show a reduction of at least 10% relative to baseline across all fuels combined. The envelope-only measure package shows a reduction in site energy consumption of every fuel relative to baseline, as the retrofitted envelopes lead to less HVAC site energy consumption without changes to the HVAC systems. The other packages all show increases in modeled electricity consumption and decreases in modeled consumption of the other fuels as much of the site energy consumption of non-electric fuels is replaced by a smaller amount of site consumption of electricity. In the measure packages that include heat pumps, heat pump water heaters, envelope work, and electric appliances, nearly all site energy consumption of non-electric fuels is replaced by a smaller total amount of site consumption of electricity.

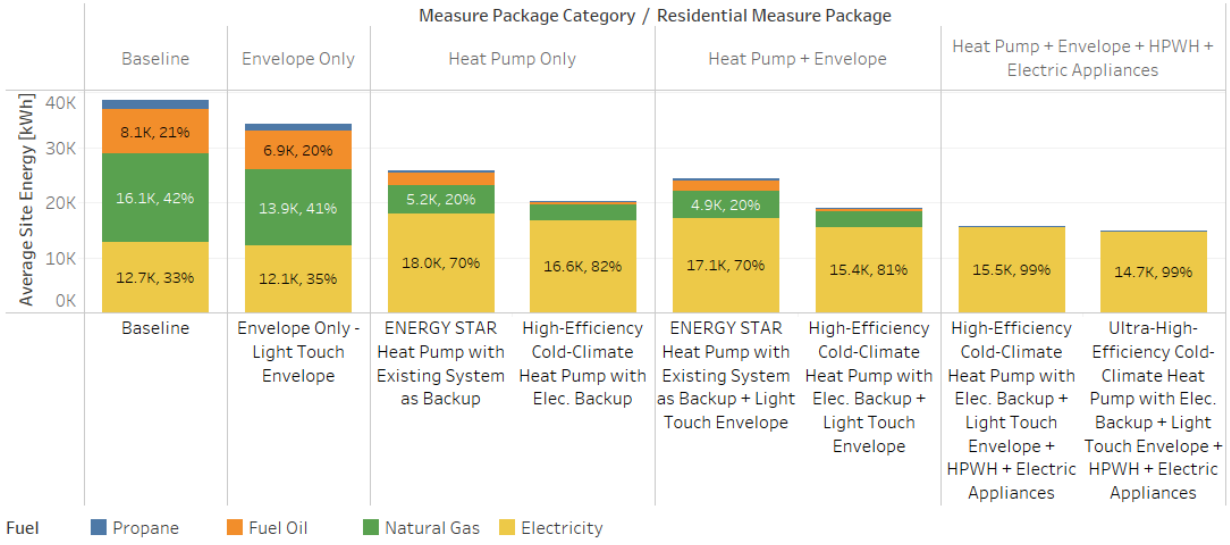


Figure 5. Average modeled site energy consumption for single-family houses in the study area, and percentage of the site energy consumed by each fuel. Note that the average across all houses is shown before and after the measure package is applied. Houses that did not have the measure package applied are included.

Figure 6 shows the total, study-area-wide modeled site energy consumption in single-family houses by end use and measure package. The total site HVAC energy consumption decreases between baseline and each measure package. Water heating also shows a visible decrease in the last two measure

packages. For all measure packages that include heat pumps, the total site energy consumption with the measure package applied is less than the HVAC site energy consumption alone in baseline.

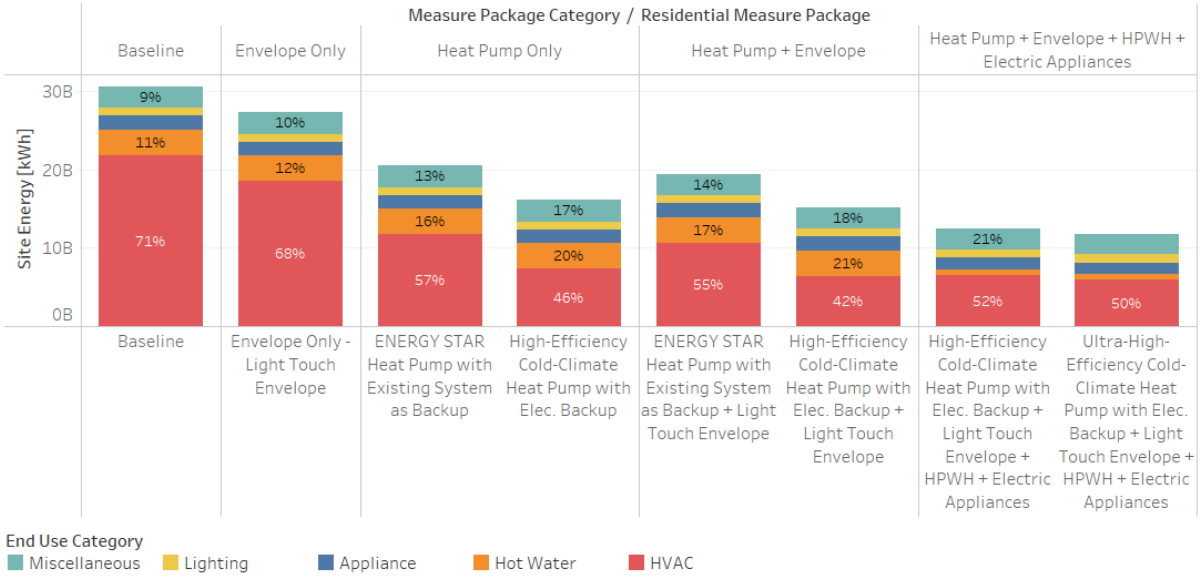


Figure 6. Total modeled site energy consumption for all single-family houses across the study area, and percentage of the site energy used for each category of end use.

Figure 7 shows the interquartile range of modeled first costs by measure package.

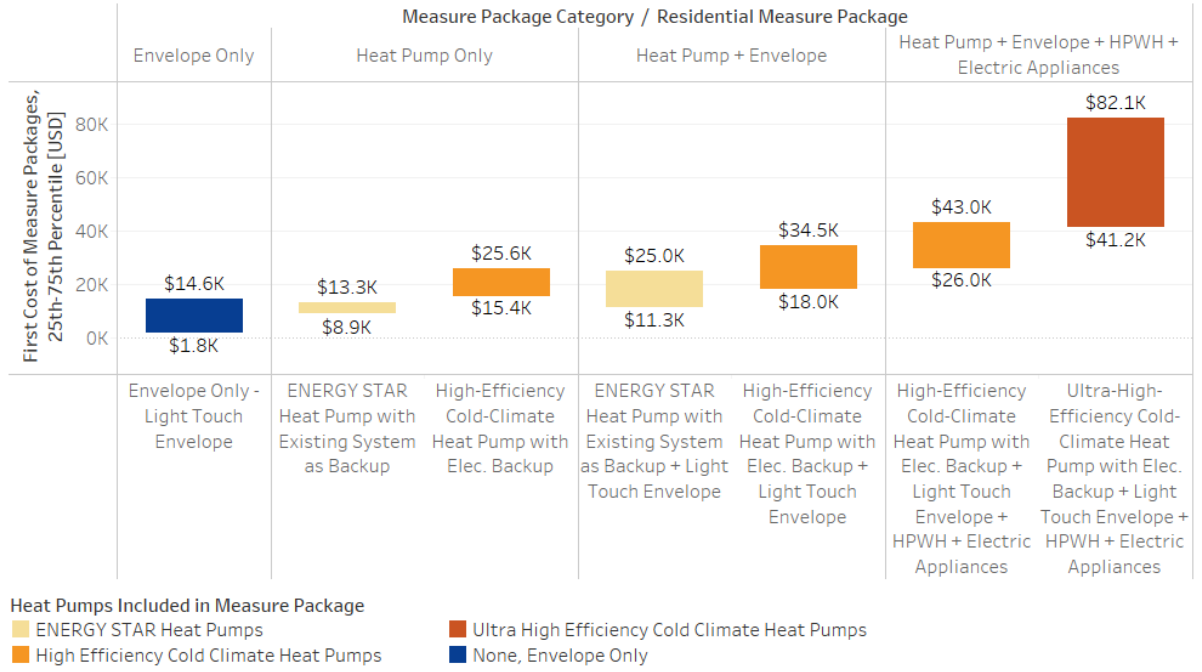


Figure 7. Interquartile range of modeled cost to implement retrofit measure packages in each applicable house in the study area. All costs are calculated using information provided by an NREL subcontractor, ICF, specific to this project. The results estimate that half of all houses' costs would fall within this range, a quarter would fall above it, and a quarter below it. Cost ranges are due to house-to-house variations only (such as size of heating system or attic size). They do not reflect other real-world cost variations such as cost differences between contractors or quarter-to-quarter differences in material costs. They also do not include any rebates, incentives, or tax credits.

Figure 8 shows the direction of energy utility bill changes by original heating fuel, original cooling system type, and measure package. All houses with original heating fuel of electricity show modeled energy utility bill reductions in these four packages. Nearly all houses with original heating fuels of fuel oil or propane also show modeled energy utility bill reductions. For houses with original heating fuel of natural gas, the type of heat pump and the original cooling type both show strong correlations with the proportion of households seeing energy utility bill increases. Bill increases are much more common with lower-efficiency heat pumps, and without existing full-house cooling. Any package that includes a heat pump provides full-house cooling to the houses it applies to, which is a new energy service for houses that do not have AC or that have ACs that only cool part of the house (such as most room ACs).

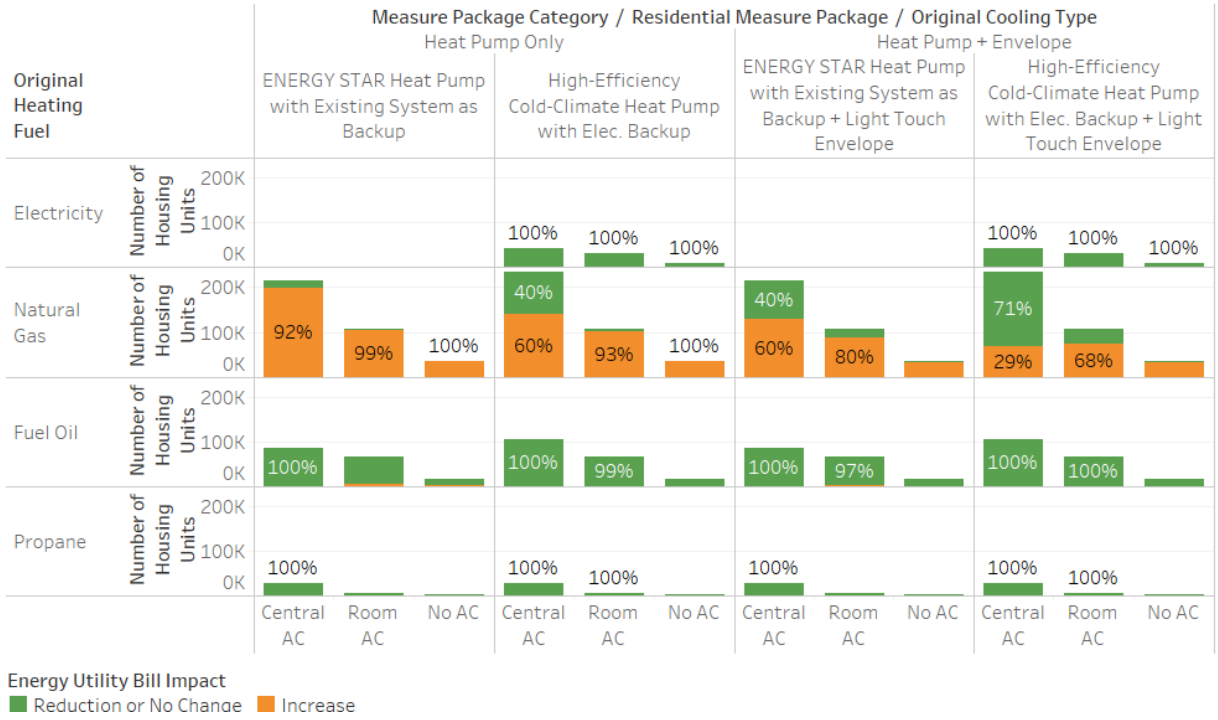


Figure 8. Number of occupied single-family houses by modeled annual energy utility bill impact direction for four of the measure packages, by original heating fuel and original cooling type. Note that the heat pump measures that use existing heating systems as backup are not applied to houses with original heating fuel of electricity in ResStock 2024 Release 2.

Beyond the four measure packages included in Figure 8, all occupied single-family houses see modeled energy utility bill reductions from the light touch envelope measure. This is because it decreases the load on existing energy-consuming equipment (such as furnaces and air conditioners) without adding new equipment. All other measure packages include new energy-consuming equipment, and in many cases that equipment uses a different fuel with a different utility rate. Therefore whether a household sees an energy utility bill decrease is based on the difference between the utility rates for the relevant fuels, the difference between the efficiencies of the relevant equipment, and any changes in load (e.g., caused by new insulation). No more than 14% of the houses see energy utility bill increases in the measure packages that include heat pumps, heat pump water heaters, envelope work, and electric appliances.

Figure 9 shows the distribution of modeled NPV by measure package. The only results visible with an original heating fuel of natural gas and a positive NPV are in the light touch envelope measure. For original heating fuels of electricity and fuel oil, there are a subset of houses with positive NPV visible for every measure package. These results are sensitive to all modeling inputs described in the Methodology, most notably the specific utility rates, first costs, discount rates, and analysis period.

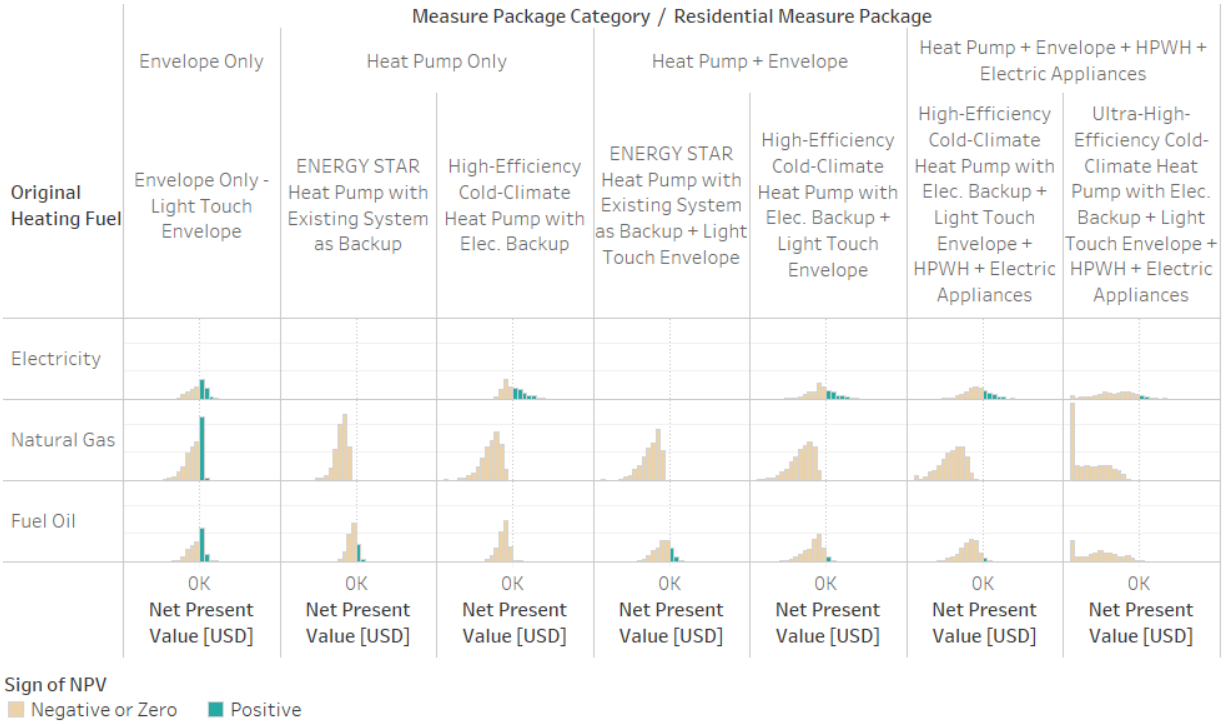


Figure 9. Distributions of modeled net present value for each measure package. The histograms have a bin size of $5,000, an overflow bin for values $75,000 and over, and an underflow bin for values of -$75,000 and below. All first costs are calculated using information provided by an NREL subcontractor, ICF, specific to this project. Cost ranges are due to house-to-house variations only (such as size of heating system or attic size). They do not reflect other real-world cost variations such as cost differences between contractors or quarter-to-quarter differences in material costs. They also do not include any rebates, incentives, or tax credits.

## Discussion

ResStock datasets contain terabytes of data that require time and experience to translate into useful and actionable insights. The right level of complexity of results for a particular analysis and target audience depends on many factors, including the scale of the project, the backgrounds and interests of the stakeholders involved, and the decisions the project is intended to inform. In the E2C Delaware Valley housing stock analysis, the team approached this by providing multiple layers of results: dozens of graphs accompanied by summary text, all the underlying data, but also key takeaways of the overall analysis consisting of just three slides.

The NREL team's key findings regarding the baseline housing stock include that there are about one million housing units in the four counties – 56% single-family detached, 21% single-family attached, 22% multifamily, and 1% mobile homes. That these housing units, as modeled by ResStock, use about 34 billion kWh of site energy annually – 41% of that being natural gas, 35% electricity, 20% fuel oil, and 4% propane – with 62% of that site energy consumption used heating, followed by water heating (11%), plug loads (7%), and cooling (5%). And that the energy consumption of that housing stock causes about 10 billion kg $CO_2e$ of emissions annually as modeled by ResStock. The key takeaways also include information on these same values at a county level.

After examining the full results provided by the NREL team, DVRPC and the community team reported that their list of key results was overlapping but distinct. Their key takeaways included the number of homes using delivered fuels (fuel oil and propane), the number of homes with minimal or no

insulation, and the energy affordability ratio results for low- and moderate-income households. The multi-level approach to presenting results allowed both sets of key takeaways to emerge from the analysis.

The collaborative approach had additional benefits as well. The NREL team was able to field questions and engage in discussions with the community team. Several team members had questions about the result that showed the study area's houses use approximately twelve times as much site energy for heating as for cooling. The team discussed the various reasons for this, including the longer heating versus cooling season, the greater typical temperature difference between indoors and outdoors when heating versus cooling, and the higher typical site efficiency of cooling versus heating equipment.

For the retrofit measure package analysis, the key takeaways presented by the NREL team include that the light touch envelope measure reduces modeled site energy consumption and emissions from each fuel countywide, shows energy utility bill reductions for all occupied houses, and shows a positive modeled NPV in 39% of occupied houses.

The key NREL takeaways for the other six measure packages, all of which include heat pumps, highlight more nuanced results. All six of these measure packages increase electricity consumption and decrease site consumption of the other four fuels, while decreasing site energy overall. These packages range from showing 8%-62% of occupied houses with increases in modeled annual energy utility bills – with bill increases being much more common with lower-efficiency heat pumps, an original heating fuel of natural gas, and without existing full-house cooling. The maximum portion of positive modeled NPV for these six measure packages is 12%, for the high-efficiency heat pump only measure. Overall, housing subsets with most of the positive modeled NPV include houses with an original heating fuel of electricity, and houses with both existing central air conditioning and an original heating fuel of fuel oil or propane. Positive modeled NPV for original heating fuel of natural gas rounds to 0% for these six measure packages.

NREL and the E2C DVRPC project team reviewed findings of the retrofit measure analysis together and presented a summary to a group of home retrofit providers convened by DVRPC in July 2025. The E2C DVRPC project team supported the NREL findings and is currently using the analysis –- and the feedback received from the home retrofit providers –- to refine and address additional research questions for inclusion in the roadmap, which has a focus on streamlining administration of weatherization, whole home repair, and other residential assistance programs in southeast Pennsylvania. The first of these is the identification of specific communities with housing likely to achieve a positive NPV.

Using insights from the housing stock analyses, the E2C DVRPC project team intends to define regional research questions that may require additional analysis. Examples include the modeling of measure packages across mobile homes (a housing subset of interest for the study but with low sample size in the study area's ResStock data) and the suitability of certain measures to be included in home repair scopes in the study area. An example of the latter is evaluating the availability of attic space to support R-60 insulation. Additionally, the E2C DVRPC team is working with NREL on refinement of assumptions of utility rates based on potential uptake scenarios.

This housing stock analysis is planned to continue through several additional efforts. One of these is an analysis of the electrical panels in the study area, and what additional work and associated costs would be required for electrical upgrades associated with the retrofit measure packages already analyzed. Another is an analysis of timeseries data for baseline and the seven measure packages, including considerations of the magnitude and timing of peaks and ramp rates. A third is an analysis of basic home or system repair costs that are foundational to implementation of the measure packages. Additionally, the project team will use the results of the ResStock analysis to inform other areas of the workplan, including analyses of funding needs, workforce capacity, and the region's supply chain.

## Disclaimer

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