Residential Facade Retrofits Modeling: Results and Documentation

Elaina Present, Eric Wilson, Carlo Bianchi, and Rachel Romero

National Renewable Energy Laboratory

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List of Acronyms

ACH50	air changes per hour at 50 Pascals
AMI	advanced metering infrastructure
CEC	California Energy Commission
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
HP-XML	Home Performance eXtensible Markup Language
HVAC	heating, ventilating, and air conditioning
IECC	International Energy Conservation Code
NPV	net present value
NREL	National Renewable Energy Laboratory
NREMDB	National Residential Efficiency Measures Database
PADD	Petroleum Administration for Defense Districts
PNNL	Pacific Northwest National Laboratory
RECS	Residential Energy Consumption Survey
SHGC	solar heat gain coefficient
SPP	simple payback period
TMY3	Typical Meteorological Year 3

Executive Summary

Older homes represent approximately 70% of the residential building stock in the United States and often have significant air leakage, inadequate insulation, and inefficient windows. There is an opportunity to improve their energy performance at the time of other planned work such as re-siding, which occurs on over two million houses annually, or during window replacement.

To evaluate the technical and economic potential of exterior insulation and window upgrades to the older portions of the U.S. housing stock at the time of other planned work on the house, this analysis used the ResStock™ tool to evaluate the energy savings, carbon emissions impacts, energy bill impacts, and capital cost of 15 retrofit cases. The retrofit cases included two exterior insulation upgrades and two window upgrades, both individually and in pairwise combinations and both with and without other work planned on the house (i.e., re-siding, window replacement). These retrofit cases were modeled on a large sample of houses representative of the over 48 million single-family detached houses in the contiguous U.S. built before 1990.

The four upgrade components included in the modeling were:

1. 1” exterior continuous insulation
2. 2” exterior continuous insulation
3. Exterior low-E storm windows
4. Triple-pane windows

The key takeaways from the analysis include:

- In Cold and Mixed-Humid climate single-family detached houses built before 1970, adding insulation at time of re-siding is cost-effective for about 15 million homes.
- In single-family detached houses built before 1970 in warmer climates, adding insulation at the time of re-siding is cost-effective in about 4 million homes.
- In single-family detached houses in the Cold and Mixed-Humid climates built before 1990, triple-pane windows are cost-effective in about 12 million homes. However, as an alternative to replacing existing windows with code-minimum windows, replacing existing windows with triple-pane windows is cost-effective in only about 4 million homes, predominantly in New England and the Upper Midwest.
- When expected increases in home resale value are taken into account, the number of homes in the Cold and Mixed-Humid climates built before 1990 showing cost-effective triple-pane window upgrades rises to about 14 million when no work is planned and 8 million as an alternative to replacing existing windows with code-minimum windows.

These conclusions can help inform retrofit recommendations and market transformation efforts in the re-siding and window replacement markets.

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1 Introduction

Older homes, built before 1992 when the U.S. Department of Energy's (DOE) Residential Building Energy Codes program was established, represent approximately 70% of residential building stock in the country and often have significant air leakage, inadequate insulation, and inefficient windows.[1] Windows and walls slowly deteriorate over time; unlike appliances or heating, ventilating, and air-conditioning (HVAC) equipment, end-of-life for these components is not always obvious. Even when thermal, moisture, and infiltration issues with a home's facade are recognized, the path toward resolving issues is often fraught with technological, financial, and social barriers. Additionally, both the problems and their solutions will typically vary by the region, climate zone, and the type of construction.

In support of DOE's work on transformational whole-building upgrades and enclosure solutions, the Pacific Northwest National Laboratory (PNNL) and the National Renewable Energy Laboratory (NREL) partnered, in collaboration with leading building science researchers and home performance entities, to identify and characterize technical and economic barriers to facade retrofits in an effort to identify market-viable facade solutions and opportunities for an actionable plan to transform the market.

Supplemental to the market characterization assessment and case studies completed by PNNL,[2,3] this technical and economic analysis adds further granularity to highlight opportunities for energy-efficient residential facade upgrades including integrated enclosure approaches and technologies.

Utilizing NREL's ResStock™ building stock energy modeling tool and complementary data sets, we performed an economic analysis for various facade upgrade combinations and strategies. This analysis considers the combined life cycle cost of re-siding and window and insulation upgrades, including both home value impacts and recurring bill savings estimates from a ResStock analysis, for varying years of home ownership.

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[1] United States Energy Information Administration. 2020. "2020 Residential Energy Consumption Survey." Available at: https://www.eia.gov/consumption/residential/data/2020/

[2] Siding and Window Retrofit Case Studies are available in the Building America Solution Center for Arizona, Michigan, Mississippi, New York, and Washington.

[3] Cort et al. 2022. *Residential Façade Upgrades: Market Assessment and Recommendations.* Pacific Northwest National Laboratory. March 2022. PNNL-32076. https://www.osti.gov/servlets/purl/1867443

2 Methodology

2.1 Overview

NREL's ResStock tool[4] models the residential building stock of the United States with its intrinsic variety. In late 2021, the development team completed the End-Use Load Profiles project,[5] which included extensive refinement of the building characteristics used to develop the building sample. This refinement was accomplished through use of a wide range of data sets, including U.S. Energy Information Administration (EIA) data, U.S. Census data, and customer advanced metering infrastructure (AMI) data, among others. This facade retrofits modeling effort included a custom run of the ResStock tool, including all the refinements from the End-Use Load Profiles project, as well as later updates. The version of ResStock used in this analysis uses the HP-XML model articulation framework.

For this analysis we generated a nationwide sample of 550,000 dwelling units covering the contiguous 48 U.S. states plus DC. This is our current standard sample size for representing the U.S. building stock, with each model representing around 242 actual U.S. dwelling units.

We then removed any samples that did not meet the following criteria:

- Single-family detached
- Occupied year-round
- Built before 1990
- Primary heating fuel of electricity, natural gas, fuel oil, or propane.

The scope of this analysis is therefore the 199,122 single-family detached house samples that met the above criteria. Each of those 199,122 house samples had more than 100 individual model input characteristics, such as size, vintage, location, wall type, window type, infiltration rate, number of occupants, thermostat setpoints, and so on. These input characteristics are based on structured probability distributions developed using data sources such as the Residential Energy Consumption Survey (RECS),[6] American Community Survey,[7] American Housing Survey,[8] and American Time Use Survey.[9] We then modeled the energy consumption of each house sample with OpenStudio®[10] and EnergyPlus,®[11] with each house sample using weather from one of more than 900 Typical Meteorological Year 3 (TMY3) weather data files based on its geographic characteristics. With each house sample representing around 242 actual houses, a total of 48.2 million homes are represented in the analysis.

We applied retrofit measures or measure packages to each house sample based on its existing

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[4] For more information, see: https://resstock.nrel.gov/.

[5] Wilson et al. 2022. *End-Use Load Profiles for the U.S. Building Stock.* https://www.nrel.gov/docs/fy22osti/80889.pdf; https://www.nrel.gov/buildings/end-use-load-profiles.html.

[6] United States Energy Information Administration. Residential Energy Consumption Surveys. https://www.eia.gov/consumption/residential/data/2009/index.php?view=microdata.

[7] United States Census Bureau. American Community Survey Data. www.census.gov/programs-surveys/acs/data.html.

[8] United States Census Bureau. American Housing Surveys. https://www.census.gov/programs-surveys/ahs.

[9] United States Bureaus of Labor Statistics. American Time Use Survey. https://www.bls.gov/tus/data-overview.htm.

[10] For more information, see: https://openstudio.net/.

[11] For more information, see: https://energyplus.net/.

(baseline) wall and window characteristics. The upgrade scenarios were specified in collaboration with the full project team and included new exterior continuous insulation rated at R-6.5 per inch (1” or 2”), replacing existing windows with triple-pane windows, and/or adding low-emissivity (low-E) exterior storm windows to existing windows. We also defined reference scenarios for comparison, including an existing (baseline) housing stock scenario, a siding replacement scenario, and a scenario of replacing a house’s existing windows with code-minimum windows. We calculated the energy and economic impacts of the upgrade scenario options compared with the reference scenarios. Comparison cases against the existing housing stock represent the impacts of upgrade work undertaken when no work on the house was planned. Comparison cases against other (non-existing) stock reference cases represent marginal costs and benefits of an upgrade or upgrade package when there was already work planned on the house. Specifically, we looked at the marginal impact of adding exterior insulation when re-siding was already planned, or of installing triple-pane windows when a full replacement of existing windows with new code-minimum windows was already planned.

Each component used in any upgrade or non-baseline reference scenario was modeled with a specific capital cost. These costs are on a per-area basis, such as per square foot wall or per square foot window. The wall and window square footages vary with different models and are reflective of variations in these housing characteristics throughout the country, but the per-area costs are constant for all modeled houses. Each upgrade or reference component was also modeled with a specific reduction in air infiltration (air changes per hour at 50 Pascals pressure differential, or ACH50). The infiltration reductions were applied to the conditioned living area and garage area. Other areas (e.g., unconditioned basements, attics, and crawlspaces) were not affected. The infiltration reductions did not have their own costs or lifetimes, as they are inherent parts of the siding replacement and the window and insulation upgrades.

2.2 Reference Scenarios

We used four different reference scenarios, including the existing (baseline) house, a planned re-siding, a planned whole-home upgrade to code-minimum windows, and both a planned re-siding and simultaneous upgrade to code-minimum windows. These reference scenarios are shown in Table 1.

Table 1. Summary of Reference Scenarios

Reference Name	Reference Name – Short	Updates and Components Included
Existing house (baseline)	Existing	None
At time of re-siding	Re-siding	• Siding update
At time of planned upgrade to code-minimum windows	Code-minimum windows	• Code-minimum windows
At time of planned res-siding and upgrade to code-minimum windows	Re-siding and code windows	• Siding update • Code-minimum windows

2.3 Upgrade Scenarios

This analysis focused on four individual upgrades, two for walls and two for windows. For walls these included 1” exterior continuous insulation rated at R-6.5 per inch and, separately, 2” exterior continuous insulation rated at R-6.5 per inch. For windows, these included a window replacement upgrade using triple-pane windows (traditional, not thin triples), and an upgrade of adding exterior low-E storm windows to existing windows. We also considered four packages consisting of pairwise combinations of one wall and one window upgrade measure. These upgrade scenarios are shown in Table 2.

We analyzed most upgrade scenarios in both a comparison case to the existing housing stock reference scenario and a second comparison case to an appropriate counterfactual reference scenario. For wall insulation, this counterfactual reference scenario is re-siding the house without adding any new insulation. This allows us to show results both from adding insulation without other work planned on the house and the marginal cost and energy impact of adding insulation at the time of planned re-siding. Over two million houses have their siding replaced each year.[12] For triple-pane windows, this counterfactual reference scenario is planned work of replacing existing windows with code-minimum windows. This allows us to show results both of replacing existing windows with triple-paned windows without other work planned on the house and the marginal cost and energy impact of replacing windows with triple-pane windows when replacing existing windows with code-minimum windows was already planned. Approximately two million houses have their windows replaced each year.[13] For upgrade packages with both an insulation upgrade and a triple-pane upgrade, we use a reference scenario that includes both re-siding and an upgrade to code-minimum windows. The low-E exterior storm window upgrade is the exception to this approach—it is looked at only in comparison to the existing house, and packages with both an insulation component and low-E storms are compared to the existing stock and the re-siding only reference scenario.

All of upgrade scenarios are shown in Table 2 along with their associated upgrade components, and the reference scenarios they are associated with to make retrofit cases.

[12] United States Census Bureau. 2021. American Housing Survey 2021 National Public Use File. https://www.census.gov/programs-surveys/ahs/data/2021/ahs-2021-public-use-file--puf-/ahs-2021-national-public-use-file--puf-.html.
[13] United States Census Bureau. 2021. American Housing Survey 2021 National Public Use File. https://www.census.gov/programs-surveys/ahs/data/2021/ahs-2021-public-use-file--puf-/ahs-2021-national-public-use-file--puf-.html.

Table 2. Summary of the Retrofit Cases Included in This Analysis, Including the 8 Upgrade Scenarios, Their Included Updates and Components, and the Reference Scenarios Considered for Each

Upgrade Scenario Name	Updates and Components Included	Reference Scenarios
1" Insulation	• Siding update • Insulation upgrade: 1” continuous insulation	- Existing house - At time of re-siding
2" Insulation	• Siding update • Insulation upgrade: 2” continuous insulation	- Existing house - At time of re-siding
Storm windows	• Exterior low-E storm windows	- Existing house
Triple-pane windows	• Triple-pane windows	- Existing house - Code-minimum windows
Exterior storms + 1" Insulation + re-siding *(Package 1)*	• Siding update • Insulation upgrade: 1” exterior continuous insulation • Windows upgrade: low-E storm windows	- Existing house - At time of re-siding
Triple-pane + 1" Insulation + re-siding *(Package 2)*	• Siding update • Insulation upgrade: 1” exterior continuous insulation • Windows upgrade: triple-pane windows	- Existing house - Re-siding + code-minimum windows
Exterior storms + 2" Insulation + re-siding *(Package 3)*	• Siding update • Insulation upgrade: 2” exterior continuous insulation • Windows upgrade: low-E storm windows	- Existing house - At time of re-siding
Triple-pane + 2" Insulation + re-siding *(Package 4)*	• Siding update • Insulation upgrade: 1” exterior continuous insulation • Windows upgrade: low-E storm windows and exterior shading	- Existing house - Re-siding + code-minimum windows

2.4 Retrofit Component Configuration

Each retrofit component was defined for the analysis in terms of technical specifications, applicability criteria, cost, and other characteristics as described in this section.

2.4.1 Reference Scenario Component Configurations

2.4.1.1 Siding Update

We defined siding update logic and applied it to all modeled homes that have siding or an exterior finish, based on the existing siding/exterior finish and no other building characteristics. PNNL advised NREL on the update logic, which is shown in Table 3. Homes without siding, cladding, or stucco were not eligible for the siding update or the insulation upgrade—these are houses with brick or concrete structural walls and no exterior finish and comprised 33,994 of the 199,122 models in this analysis. The energy-related effects of re-siding alone include changes in reflectivity and surface properties and decreases in air infiltration.

Table 3. Siding Update Types and Applicability

Existing Siding	Updated Siding
Aluminum, Light[14]	Fiber-Cement, Light
Brick, Light	Stucco, Light
Brick, Medium/Dark	Stucco, Light
Fiber-Cement, Light	Fiber-Cement, Light (no change)
Shingle, Asbestos, Medium	Vinyl, Light
Shingle, Composition, Medium	Vinyl, Light
Stucco, Light	Stucco, Light (no change)
Stucco, Medium/Dark	Stucco, Light
Vinyl, Light	Vinyl, Light (no change)
Wood, Medium/Dark	Fiber-Cement, Light
None	*Not eligible for siding update or insulation upgrade*

The costs used for the siding update were established based on values in the National Residential Efficiency Measures Database (NREMDB) for replacing exterior finish, varying based on which siding material was used for the new siding, and were vetted with the project team. The costs used for the siding update are shown in Table 4, along with the infiltration reduction.

Table 4. Costs and Infiltration Reduction for Re-Siding Reference Scenario

Updated Siding	Cost *per square foot exterior wall area*	Infiltration Reduction
Fiber-Cement, Light	$4.00	19%
Stucco, Light	$5.70	19%
Vinyl, Light	$3.30	19%

We modeled a 19% infiltration reduction associated with re-siding, the same as for new exterior insulation with re-siding, as shown in Table 8.

2.4.1.2 Code-Minimum Windows

The code-minimum windows retrofit component represents replacing a house's existing windows with windows compliant with the applicable building code.

Our team reviewed the building codes of the 48 states covered in this project, as well as Washington, D.C., for their window requirements as of fall 2022. We found that the majority of states use one of the versions of the International Energy Conservation Code (IECC) or specify prescriptive requirements that are equivalent to using one of the IECC versions. Other states define their own requirements that are not directly equivalent to using one of the IECC versions. We implemented each of these specific window performance levels in our code-minimum

[14] "Light," "Medium," etc. refer to color.

window modeling. Some states have no statewide building codes; after discussion with the broader project team, we modeled these states using IECC 2006. Table 5 shows this state-building code relationship as used in this analysis.

Table 5. Summary of Energy Codes Used for Each U.S. State

Code	States
IECC 2021	CT, MT, NJ
IECC 2018	DE, IL, IN, MD, NE, NH, NM, NV, NY, OH, OR[15], PA, VA
IECC 2015	AL, FL, GA, ME, MN, TX, UT
IECC 2012	IA
IECC 2009	AR, KY, LA, SC, TN, WI, WV
No statewide code *Modeled using IECC 2006*	AZ, CO, KS, MO, MS, ND, SD, WY
State-specific code	CA, DC, ID, MA, MI, NC, OK, RI, VT, WA

The IECC requirements vary by climate zone. IECC climate zones changed in 2021, but the changes do not affect any of the states that use the 2021 IECC[16] for window performance requirements, so we used the older definitions of IECC climate zones. IECC does not specify a solar heat gain coefficient (SHGC) in the Marine climates or in the colder climates. Some versions of the IECC, including the 2015 one used by Florida at the time of this work, do not specify a U-factor for climate zone 1A, which comprises Miami and its surroundings. We therefore worked with the project team to specify SHGC and U-factor values to use where they were not provided by the code. Together with the team we selected 0.3 SHGC to use wherever SHGC was not specified and U-value 0.65 to use for climate zone 1A in the years no value was specified. A sensitivity analysis showed that choosing other similar values would have minimal impact on the results.

Table 6 shows the relationship between code and window specifications for the code-minimum windows reference case. The bolded, underlined cells are values that were not provided in the relevant code and so were supplied by the project team.

[15] For existing buildings.
[16] See Figure 5 of PNNL's September 2022 report *Guide to Determining Climate Zones by County: Building America and IECC 2021 Updates.* Available at: https://www.osti.gov/servlets/purl/1893981.

Table 6. Summary of U-Value and SHGC for Each Energy Code Used in This Analysis, by Climate Zone

Bold, underlined cells are values that were not provided by the code and so supplied by the project team.

	IECC Climate Zone													
Code	1		2		3		4 except Marine		5 and Marine 4		6		7 & 8	
	U-value	SHGC	U-value	SHGC	U-value	SHGC	U-value	SHGC	U-value	SHGC	U-value	SHGC	U-value	SHGC
IECC 2021	0.5	0.25	0.4	0.25	0.3	0.25	0.3	0.4	0.3	0.4	0.3	**0.3**	0.3	**0.3**
IECC 2018	**0.65**	0.25	0.4	0.25	0.32	0.25	0.32	0.4	0.3	**0.3**	0.3	**0.3**	0.3	**0.3**
IECC 2015	**0.65**	0.25	0.4	0.25	0.35	0.25	0.35	0.4	0.32	**0.3**	0.32	**0.3**	0.32	**0.3**
IECC 2012	**0.65**	0.25	0.4	0.25	0.35	0.25	0.35	0.4	0.32	**0.3**	0.32	**0.3**	0.32	**0.3**
IECC 2009	1.2	0.3	0.65	0.3	0.5	0.3	0.35	**0.3**	0.35	**0.3**	0.35	**0.3**	0.35	**0.3**
IECC 2006	1.2	0.4	0.75	0.4	0.65	0.4	0.4	**0.3**	0.35	**0.3**	0.35	**0.3**	0.35	**0.3**
ID									0.32	**0.3**	0.3	**0.3**		
MA									0.3	**0.3**				
NC					0.35	0.3	0.35	0.3	0.35	**0.3**				
OK					0.38	0.3	0.32	0.40						
RI									0.3	**0.3**				
WA[17]									0.3	**0.3**				
The following states' energy codes do not use IECC climate zones for determining code-minimum window specifications														
CA	U-value: 0.3 / SHGC: 0.23 for CEC[18] climate zones 2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15													
	U-value 0.3 / SHGC **0.3** for CEC climate zones 1, 3, 5, 16													
DC	U-value 0.3 / SHGC 0.4													
MI	U-value 0.32 / SHGC 0.3													
VT	U-value 0.3 / SHGC 0.3													

In the code-minimum window reference case, we replaced any lower-performing window with the appropriate code-minimum window based on the model house's state's requirements (per Table 5) and climate zone. Clear storm windows were not preserved after the code-minimum window upgrade. We also modeled an infiltration reduction associated with window replacement. These were the same as for triple-pane windows, shown in Table 9: 30% whole-home infiltration reduction if replacing a single-pane window and 15% whole-home infiltration reduction if replacing a double-pane window, regardless of the presence of clear storm windows before the upgrade. We used baseline window type to determine infiltration reduction as an approximate proxy for the age of the window. Window operation type is another important

[17] Note that the counties in Washington that IECC lists as in climate zone 6, the Washington energy code lists as being in climate zone 5.
[18] Note that CEC refers to California Energy Commission climate zones.

indicator of associated infiltration at the window, but that characteristic is not currently available in ResStock.

We used the following costs for code-minimum windows. These were calculated by using the average costs in NREMDB for each U-value level, scaled to the $46 for triple-pane windows that had been informed by work by ENERGY STAR[19] and affirmed through the consensus among project stakeholders, and then rounded to the nearest $0.10.

Table 7. Summary of Costs per Square Foot for Code-Minimum Window Reference Scenario

U-Value	Cost *per square foot window area*
0.32	$35.50
0.30	$36.30
0.35	$31.50
0.38	$29.45
0.40	$27.40
0.50 and above	$26.60

2.4.2 Upgrade Scenario Component Configurations

2.4.2.1 Insulation Upgrade

Working with the project team, we defined two insulation upgrades for walls, with specifications and cost shown in Table 8. The insulation costs are based on polyisocyanurate insulation using the high end of the range listed in the NREMDB[20] and are consistent with feedback provided by contractors in a March 2021 workshop.

Table 8. Insulation Upgrade Specifications and Cost

Insulation Upgrade	R-Value	Infiltration Reduction	Cost *per square foot exterior wall area*
1” exterior continuous insulation	6.5	19%	$1.40[21]
2” exterior continuous insulation	13	19%	$1.90[22]

These insulation upgrades apply to any model home with less than R-19 total existing insulation in/on the walls and existing siding, cladding, or stucco, and that meets the project-wide criteria for inclusion. Homes with R-19 or higher existing insulation or that did not have existing siding, cladding, or stucco did not receive insulation upgrades but were still eligible for other upgrades (e.g., windows). All insulation upgrades included a 30-year lifetime.

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[19] U.S. Environmental Protection Agency. 2021. *ENERGY STAR Windows, Doors, and Skylights Version 7.0 Criteria Analysis*. https://www.energystar.gov/sites/default/files/asset/document/ES_Residential_WDS_Draft%201_Criteria%20Analysis%20Report.pdf.
[20] https://remdb.nrel.gov/
[21] https://remdb.nrel.gov/measures.php?gId=12&ctId=410&scId=6547&acId=6552
[22] https://remdb.nrel.gov/measures.php?gId=12&ctId=410&scId=6547&acId=6553

The baseline (pre-retrofit) wall configurations in ResStock are listed below, not including their exterior finish. The options that meet the insulation portion of the wall upgrade criteria for this analysis are bold.

Wood Stud, Uninsulated	**CMU, 6-in Hollow, Uninsulated**	**Brick, 12-in, 3-wythe, Uninsulated**
Wood Stud, R-7	**CMU, 6-in Hollow, R-7**	**Brick, 12-in, 3-wythe, R-7**
Wood Stud, R-11	**CMU, 6-in Hollow, R-11**	**Brick, 12-in, 3-wythe, R-11**
Wood Stud, R-15	**CMU, 6-in Hollow, R-15**	**Brick, 12-in, 3-wythe, R-15**
Wood Stud, R-19	CMU, 6-in Hollow, R-19	Brick, 12-in, 3-wythe, R-19

Figure 1 shows the distribution of houses in the analysis with each baseline wall configuration, by climate zone, rounded to the nearest percent.

	Building America Climate Zone				
Baseline Wall	Cold & Very Cold	Mixed-Humid	Marine	Hot-Dry & Mixed-Dry	Hot-Humid
Wood Stud, Uninsulated	45%	59%	74%	64%	38%
Wood Stud, R-7	12%	10%	10%	10%	6%
Wood Stud, R-11	12%	13%	13%	17%	12%
Wood Stud, R-15	2%				
Wood Stud, R-19	3%	2%	1%	1%	1%
Brick, 12-in, 3-wythe, Uninsulated	16%	11%	1%	4%	20%
Brick, 12-in, 3-wythe, R-7	4%	2%	0%	1%	5%
Brick, 12-in, 3-wythe, R-11	2%	1%	0%	1%	9%
Brick, 12-in, 3-wythe, R-15	0%				
Brick, 12-in, 3-wythe, R-19	0%	0%		0%	0%
CMU, 6-in Hollow, Uninsulated	2%	1%	0%	2%	5%
CMU, 6-in Hollow, R-7	1%	0%	0%	0%	1%
CMU, 6-in Hollow, R-11	0%	0%	0%	0%	2%
CMU, 6-in Hollow, R-15	0%				
CMU, 6-in Hollow, R-19	0%	0%		0%	0%

Figure 1. Distribution of wall type for the baseline homes modeled in this analysis, by climate zone, rounded to the nearest percent

2.4.2.2 Windows Upgrades

The project team defined two window upgrades, exterior low-E storm windows and triple-pane windows, with specifications and cost shown in Table 9. We used three different triple-pane windows, applied based on the state's code requirements for window performance. The state specifications used are shown in Table 5 and Table 6, and the applicability is shown in Table 10. The triple-pane windows are traditional triples, not the newly available thin triples.

Table 9. Window Upgrade Specifications and Cost

Window Upgrade	Baseline Window	U-Factor	SHGC	Infiltration Reduction	Cost *per square foot window area*
Low-E storm windows	Single, clear, metal	0.57	0.47	15% if added 10% if replacing a clear storm window	$14.70[23]
Low-E storm windows	Single, clear, non-metal	0.36	0.46		$14.70
Low-E storm windows	Double, clear, metal	0.49	0.44		$14.70
Triple-pane, low-E, insulated, argon, high-gain	Any eligible window	0.18	0.40	30% if replacing a single-pane window 15% if replacing a double-pane window Regardless of the presence of clear storm windows before the upgrade	$46.00[24]
Triple-pane, low-E, insulated, argon, low-gain	Any eligible window	0.17	0.27		
Triple-pane, low-E, insulated, argon, very low gain	Any eligible window	0.17	0.23		

The baseline (pre-retrofit) window types are listed below (Table 10). We focused on the lowest-performing window types that would benefit the most from replacement, although energy savings from new windows can be considerable from other baseline window types as well. Homes with window types that did not receive window upgrades were still eligible for other upgrades (e.g., insulation). All window upgrades included a 30-year lifetime.

[23] $14.70 per ft^2 is the average of several sources underlying NREMDB for professionally installed low-E storm windows and was reviewed by PNNL and DOE collaborators.
[24] $46.00 per ft^2 is based on the average NREMDB window replacement labor cost of $21.08 per ft^2 with a 10% increase, plus the average NREMDB material cost of $18.31 per ft^2 for double-pane, low-E (high-gain) windows with insulated frames and argon fill, with a $4.50 adder for the additional pane. Coincidentally, $46.00 per ft^2 is also the middle of the range for non-insulated-frame triple-pane windows in the REMDB (https://remdb.nrel.gov/measures.php?gId=16&ctId=190&acId=2077). These costs were chosen for the analysis and vetted in 2022 and reflect the market at that time, they do not include the impacts on cost of triple-pane windows becoming more common with the ENERGY STAR v7 window specification.

Table 10. Window Upgrade Applicability

Baseline Window	Low-E Storm Window Upgrade	Triple-Pane Window Upgrade
Single, clear, metal	Single, clear, metal, exterior low-E storm	Triple-pane, low-E, insulated, argon, high-gain, for states with SHGC requirements ≥ 0.40 Triple-pane, low-E, insulated, argon, low-gain, for states with SHGC requirements ≥ 0.27 and < 0.40 Triple-pane, low-E, insulated, argon, very low gain, for states with SHGC requirements < 0.27
Single, clear, metal, exterior clear storm	Single, clear, metal, exterior low-E storm	
Single, clear, non-metal	Single, clear, non-metal, exterior low-E storm	
Single, clear, non-metal, exterior clear storm	Single, clear, non-metal, exterior low-E storm	
Double, clear, metal, air	Double, clear, metal, air exterior low-E storm	
Double, clear, metal, air, exterior clear storm	No upgrades applied	
Double, clear, non-metal, air	No upgrades applied	
Double, clear, non-metal, air, exterior clear storm	No upgrades applied	
Double, low-E, non-metal, air, medium-gain	No upgrades applied	
Triple, low-E, non-metal, air, low-gain	No upgrades applied	

Figure 2 shows the distribution of houses in the analysis with each baseline window type, by climate zone, rounded to the nearest percent.

	Building America Climate Zone				
Baseline Window	Cold & Very Cold	Mixed-Humid	Marine	Hot-Dry & Mixed-Dry	Hot-Humid
Single, Clear, Metal	6%	13%	15%	23%	34%
Single, Clear, Metal, Exterior Clear Storm	1%	1%	1%	1%	2%
Single, Clear, Non-metal	24%	22%	24%	25%	24%
Single, Clear, Non-metal, Exterior Clear Storm	3%	2%	2%	2%	1%
Double, Clear, Metal, Air	10%	13%	13%	16%	16%
Double, Clear, Metal, Air, Exterior Clear Storm	1%	1%	1%	1%	1%
Double, Clear, Non-metal, Air	25%	22%	21%	15%	11%
Double, Low-E, Non-metal, Air, M-Gain	23%	21%	20%	14%	10%
Double, Clear, Non-metal, Air, Exterior Clear Storm	6%	3%	3%	2%	1%
Triple, Low-E, Non-metal, Air, L-Gain	2%	2%	1%	0%	0%

Figure 2. Distribution of window type for the baseline homes modeled in this analysis, by climate zone, rounded to the nearest percent

2.4.3 Infiltration

All baseline infiltration levels received the same percent reductions, which varied based on the insulation and/or window upgrades applicable to the home based on the house model's baseline wall and window type.

Figure 3 shows the baseline infiltration options and the percent of homes modeled at each air leakage level. ResStock's distribution of infiltration is built using data from the Residential Diagnostics Database (ResDB),[25] with dependencies on IECC climate zone, home size, and vintage.

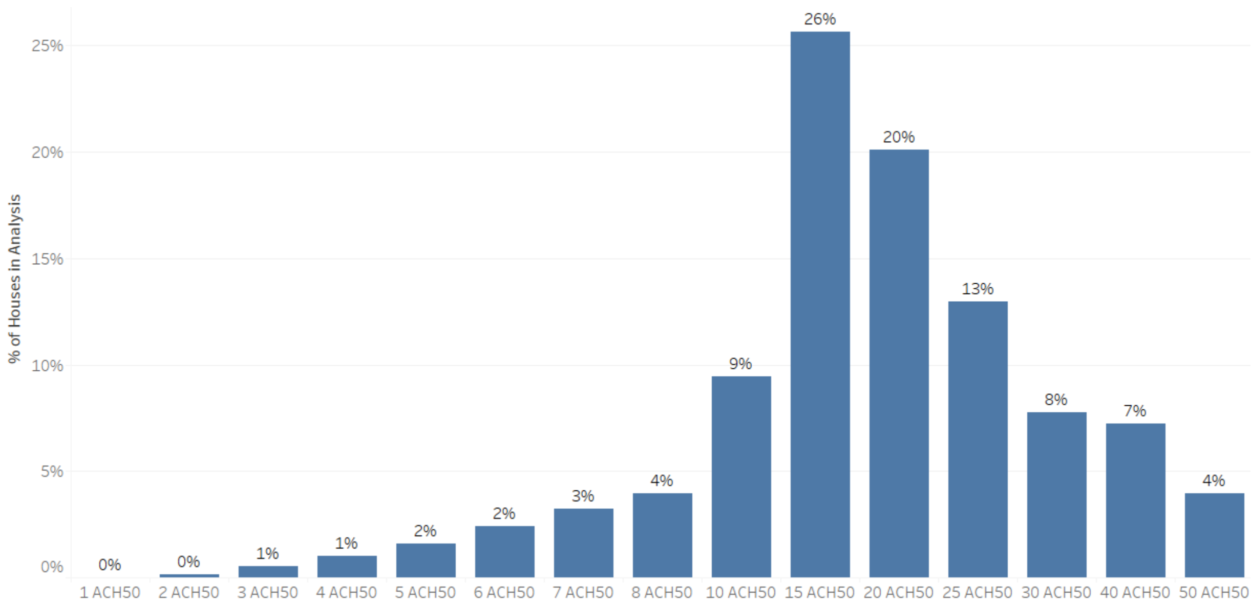

Figure 3. Distribution of envelope air leakage values (ACH50) for the baseline homes modeled in this analysis

Data derived from http://resdb.lbl.gov

2.5 Model Runs

We conducted one model run of all sample houses for each reference or upgrade scenario, including the baseline. The number of sample houses that was eligible for each upgrade model run based on the previously outlined criteria is shown in Figure 4.

[25] http://resdb.lbl.gov

Building America Climate Zone	Vintage	Existing Applicable	Re-Siding Applicable	Code Compliant Windows Applicable	Re-siding & code-minimum windows Applicable	1″ insulation + re-siding Applicable	2″ insulation + re-siding Applicable	Exterior low-E storm windows Applicable	Triple pane windows Applicable	Exterior storms + 1″ insulation + re-siding Applicable	Triple pane + 1″ insulation + re-siding Applicable	Exterior storms + 2″ insulation + re-siding Applicable	Triple pane + 2″ insulation + re-siding Applicable
Cold & Very Cold	Before 1950	27,935	22,716	13,548	25,194	22,716	22,716	13,548	13,548	25,194	25,194	25,194	25,194
	1950-1969	27,814	20,936	12,327	23,939	20,936	20,936	12,327	12,327	23,939	23,939	23,939	23,939
	1970-1989	22,269	16,198	8,008	18,282	16,198	16,198	8,008	8,008	18,282	18,282	18,282	18,282
Mixed-Humid	Before 1950	14,410	12,453	7,639	13,482	12,453	12,453	7,639	7,639	13,482	13,482	13,482	13,482
	1950-1969	21,506	18,158	10,980	19,939	18,158	18,158	10,980	10,980	19,939	19,939	19,939	19,939
	1970-1989	22,034	17,976	10,936	20,100	17,976	17,976	10,936	10,936	20,100	20,100	20,100	20,100
Marine	Before 1950	2,936	2,888	1,632	2,914	2,888	2,888	1,632	1,632	2,914	2,914	2,914	2,914
	1950-1969	3,934	3,863	2,200	3,894	3,863	3,863	2,200	2,200	3,894	3,894	3,894	3,894
	1970-1989	3,770	3,664	1,970	3,717	3,664	3,664	1,970	1,970	3,717	3,717	3,717	3,717
Hot-Dry & Mixed-Dry	Before 1950	4,214	4,026	2,662	4,150	4,026	4,026	2,662	2,662	4,150	4,150	4,150	4,150
	1950-1969	9,130	8,572	6,003	8,964	8,572	8,572	6,003	6,003	8,964	8,964	8,964	8,964
	1970-1989	9,240	8,483	6,575	9,034	8,483	8,483	6,575	6,575	9,034	9,034	9,034	9,034
Hot-Humid	Before 1950	3,953	3,253	2,991	3,797	3,254	3,254	2,991	2,991	3,797	3,797	3,797	3,797
	1950-1969	10,643	7,738	8,294	9,995	7,738	7,738	8,294	8,294	9,995	9,995	9,995	9,995
	1970-1989	15,334	9,789	11,898	14,050	9,789	9,789	11,898	11,898	14,050	14,050	14,050	14,050
Grand Total		**199,122**	**160,713**	**107,663**	**181,451**	**160,714**	**160,714**	**107,663**	**107,663**	**181,451**	**181,451**	**181,451**	**181,451**

Figure 4. Number of ResStock sample houses eligible for each of the retrofit components, aggregated by climate zone and vintage range. A total of 199,122 sample houses were eligible for one or more upgrades in this analysis, representing around 242 actual U.S. houses each, for a total of 48.2 million homes represented in this analysis.

2.6 Economic Inputs

All energy price data are from 2021.

2.6.1 Utility Costs

Residential Electricity Costs

We downloaded data from NREL's Utility Rate Database[26] in November 2021 to calculate the customer-weighted average fixed monthly electricity charge across all utilities in the database:

$$\frac{\sum Fixed\ electric\ charge\ x\ Number\ of\ customers}{\sum Number\ of\ customers}$$

This came out to approximately $10/customer/month.

We downloaded EIA state average residential electricity data[27] including total revenue (in thousands of dollars), total sales (in MWh), and total customers (qty). We then calculated the variable electricity rate for each state:

$$\frac{Total\ Revenue - (Fixed\ Cost\ x\ Number\ of\ Customers)}{Total\ Sales}$$

This resulted in a per-unit volumetric residential electric utility customer rate for each state that varied from 9.1 ¢/kWh in Washington State to 21.2 ¢/kWh in Massachusetts.

[26] OpenEI. 2023. "Utility Rate Database." https://openei.org/wiki/Utility_Rate_Database
[27] U.S. Energy Information Administration. 2023. "Historical State Data." https://www.eia.gov/electricity/data/state/

Residential Natural Gas Costs
For natural gas bill calculations, we used the American Gas Association's 2015 value of \$11.25/customer/month[28] for the fixed portion of the utility bill (generally referred to as the "customer charge"). We downloaded 2021 EIA data by state on price,[29] consumption,[30] and number of customers,[31] and then calculated the volumetric rate for each state as:

$$\frac{(Consumption\ x\ Price) - (Fixed\ Cost\ x\ Number\ of\ Customers)}{Total\ Sales}$$

The results ranged from \$0.49/therm in Idaho to \$1.64/therm in Florida.

Residential Fuel Oil and Residential Propane Costs
We downloaded weekly data from the 2021–2022 winter from EIA for residential fuel oil[32] and residential propane,[33] and averaged the data over the available weeks. When state-level data were not available, we used data from the state's Petroleum Administration for Defense Districts (PADD) region. When PADD region data were not available, we used U.S. national average values.

2.7 Calculating Energy Savings and Economic Results

We calculated first-year energy savings, first-year bill savings, simple payback period, and net present value for each retrofit case included in this analysis. We did not perform calculations for houses that did not receive any part of a specific upgrade, and those houses are accordingly not included in summary statistics such as means and medians. Similarly, if a house was not served by a specific fuel, that fuel was not included.

Summary statistics are therefore calculated across houses that received any part of that upgrade and that are served in part by that fuel. For example, for the 1" insulation and low-E storm windows upgrade, houses that were not eligible for the insulation portion of the upgrade (e.g., because they had baseline R-19 wall insulation) but were eligible for the low-E storm window portion, had their energy savings aggregated with homes that received all portions of the upgrade. This impacts all results in this analysis including downstream economic analyses as well. It means that each of the package upgrades shows less energy savings than it would if we had confined the analysis to only homes that were eligible for all portions of the upgrade, and that in some cases a package upgrade can show less aggregated savings than one of its component upgrade measures.

If a house had some portion of an upgrade applied but no portion of the relevant reference case, the existing/baseline reference upgrade value was used instead. For example, a home that was eligible for window upgrades but not siding or insulation upgrades would have results for the 1"

[28] American Gas Association. "Natural Gas Utility Rate Structure: The Customer Charge Component – 2015 Update." https://downloads.regulations.gov/EERE-2012-BT-STD-0047-0068/attachment_10.pdf
[29] U.S. EIA. "Natural Gas Prices." https://www.eia.gov/dnav/ng/ng_pri_sum_a_epg0_prs_dmcf_a.htm
[30] U.S. EIA. "Natural Gas Consumption by End Use." https://www.eia.gov/dnav/ng/ng_cons_sum_a_epg0_vrs_mmcf_a.htm
[31] U.S. EIA. "Number of Natural Gas Consumers." https://www.eia.gov/dnav/ng/ng_cons_num_a_epg0_vn3_count_a.htm
[32] U.S. EIA. "No. 2 Distillate Prices by Sales Type." https://www.eia.gov/dnav/pet/pet_pri_dist_a_epd2_prt_dpgal_a.htm
[33] U.S. EIA. "Weekly Heating Oil and Propane Prices (October–March)." https://www.eia.gov/dnav/pet/pet_pri_wfr_a_EPD2F_PRS_dpgal_w.htm

insulation and storm windows package, because the storm window upgrade component would apply, but no results for the re-siding component, and so results from the existing/baseline reference upgrade would be used for the reference for that home in the re-siding reference scenario.

2.7.1 Energy Savings Calculations

We calculated the difference between the upgrade scenario and the associated reference scenario total one-year (annual) energy consumption for each house, upgrade, and fuel. We used a sign convention of a positive value representing savings. In a small number of cases, energy savings is negative, meaning that total energy consumption for the year was higher after the upgrade than it was in the baseline.

2.7.2 Energy Bill Savings Calculations

We multiplied each energy savings result by the appropriate volumetric price based on state and fuel type to calculate one year of energy bill savings.

2.7.3 Simple Payback Period Calculations

We calculated the simple payback period (SPP) for each house as the net capital cost of the upgrade (i.e., the capital cost of the upgrade minus the capital cost of the reference scenario) divided by the annual energy bill savings across all fuels.

2.7.4 Net Present Value Calculations

The net present value (NPV) calculation uses the calculated annual bill savings for the first year as the annual bill savings. It also uses the net capital cost of the upgrade, lifetime, analysis period, and real discount rate as inputs. We used an analysis period of 30 years and a real discount rate of 3.4% (5.0% nominal discount rate minus 1.6% inflation).[34] The calculation is then as follows:

$$\sum_{i=0}^{30\ years} \frac{1}{1.034^i}(cost_i - savings_i)$$

Because all the modeled facade retrofits have a modeled lifetime of 30 years, and the analysis period is also 30 years, no replacement cost or residual value component was included in the calculations.

2.8 Emissions

We included carbon emissions calculations in our model runs and calculated avoided emissions as the difference in emissions between upgrade scenarios and their associated reference scenarios. The carbon emissions factors that we used are the same as were used in the recent End-Use Savings Shapes: Residential Round 1[35] work and are described below together with their sources.

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[34] See Table 3.3 in Taylor et al. 2015. *Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes.* https://www.energycodes.gov/sites/default/files/2021-07/residential_methodology_2015.pdf.

[35] Present, Elaina, et al. 2022. "End-Use Savings Shapes: Public Dataset Release for Residential Round 1." NREL/PR-5500-84931. https://www.nrel.gov/docs/fy23osti/84931.pdf

2.8.1 Emissions Associated With Non-Electric On-Site Fuel Consumption

In harmonization with the End-Use Savings Shapes Residential Round 1 work, 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 (275.8 kg/MWh)
- Fuel oil: 195.9 lb/MMBtu (303.2 kg/MWh)

The values are from *Table 7.1.2(1) National Average Emissions Factors for Household Fuels* from draft *ANSI/RESNET/ICC 301 Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index.*[36] They include both the combustion and pre-combustion (e.g., methane leakage for natural gas) CO_2e emissions.

2.8.2 Emissions Associated With Electricity Consumption

In harmonization with the End-Use Savings Shapes Residential Round 1 work, we used four different sets of long-run marginal emissions factors from NREL's Cambium 2021[37] database. These factors and corresponding emissions results represent a single year of emissions. The emissions are calculated as an average of the annual emissions over a range of future years, and a discount rate is applied to weight the average to emphasize emissions in sooner years (closer to the present year).

Table 11. Summary of Long-Run Marginal Emissions Factors from NREL's Cambium 2021 Database Used in This Analysis

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 long-run marginal emissions from the LowRECost scenario in Cambium 2021 with a 25-year levelization period have been selected for use in ANSI/RESNET/ICC 301 *Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index.*[36]

In what is currently typical practice in ResStock work, 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 and Emissions Assessment Region geographic level. See the Cambium documentation[37] for additional information on Cambium emissions factor development and details.

[36] RESNET. 2022. "Draft PDS-01, BSR/RESNET/ICC 301-2022 Addendum B, CO_2 Index." https://www.resnet.us/about/standards/resnet-ansi/draft-pds-01-bsr-resnet-icc-301-2022-addendum-b-co2-index/

[37] Gagnon, Pieter, Will Frazier, Wesley Cole, and Elaine Hale. 2021. Cambium Documentation: Version 2021. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-81611. https://www.nrel.gov/docs/fy22osti/81611.pdf

3 Results, Aggregation, and Visuals

3.1 Model Runs

As noted previously, of the 550,000 residences generated by ResStock, 199,122 (36.2%) single-family detached homes met the criteria for this analysis and were modeled in the baseline, representing 48.2 million of the houses in the existing U.S. building stock. Each upgrade run applied to a subset of those 199,122 based on the windows and walls of the house, as shown in Figure 4.

This section shows the results for all retrofit cases in this analysis—all upgrade scenarios compared to their appropriate reference scenarios. Results for the reference scenarios themselves compared to the existing housing stock are in Appendix B using the same visualization formats. All results are aggregations across every modeled house that met the applicability criteria for the specified upgrade, including both houses that are truly good candidates for the upgrade and see considerable energy savings, and houses that are less good or bad candidates for the upgrade and will see minimal energy savings—for example because they have extremely minimal HVAC load—or even, in rare cases, energy consumption increases.

3.2 Nationwide Total Energy and Emissions Results

Total, nationwide one-year energy savings and emissions reductions if every house represented in the analysis were to be retrofit as modeled are shown in Figure 5 (energy) and Figure 6 (carbon emissions).

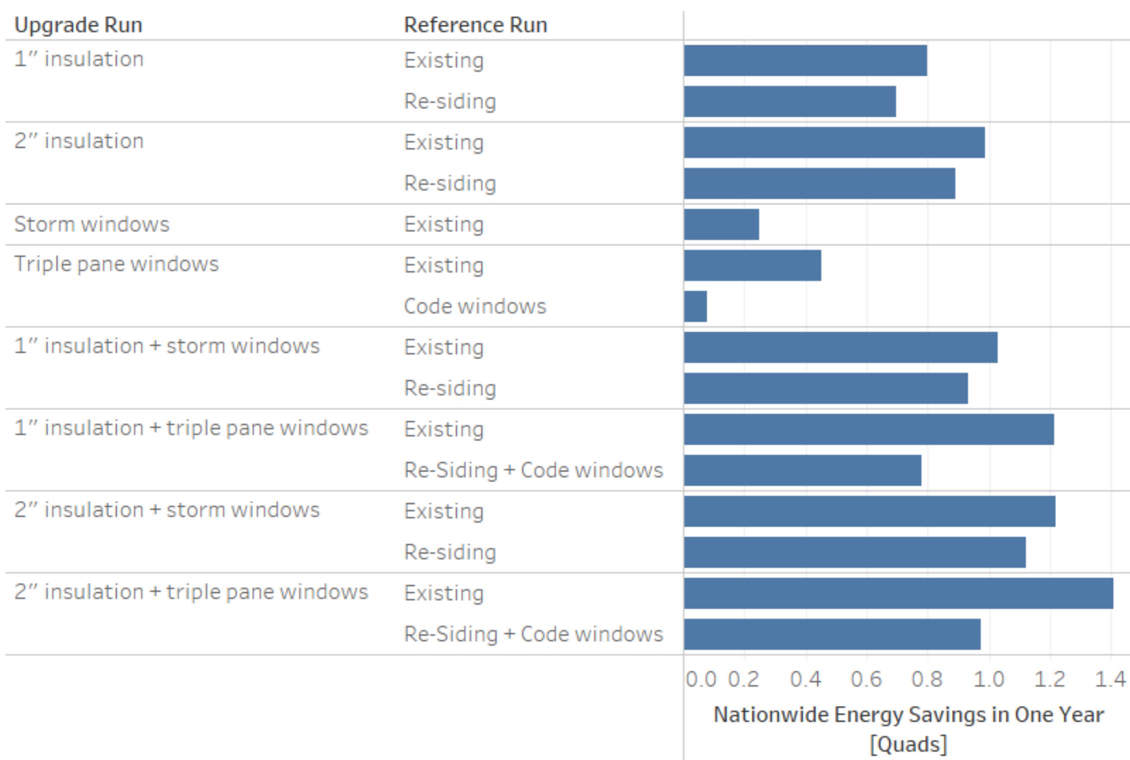

Figure 5. Total one-year nationwide energy savings if every house represented in the analysis were to have the specified retrofit case implemented

Figure 5 shows that the national energy savings potential of insulation-only measures is approximately 0.8 quads of energy for 1" insulation and nearly 1.0 quads of energy for 2" insulation when compared to the existing housing stock, and nearly as large when compared to the reference scenario of re-siding the house—approximately 0.7 and 0.9 quads of energy savings, respectively—even considering both are modeled with the same infiltration reduction. For triple-pane windows, it is a different story: retrofit to triple-pane windows has a national technical potential for the houses that meet the criteria in this analysis of over 0.4 quads of energy savings, but only approximately 0.1 quads of energy savings compared to a reference scenario of a retrofit to code windows.

Figure 6 shows national carbon emissions reduction results using one of the four different sets of emissions factors described in Section 2.8.2, the LowRECost grid scenario with a 25 year levelization period, in million metric tons of CO_2e. These results show that the different retrofit cases would show nationwide one-year long-run marginal emissions reductions ranging from 6 to 101 MMT if applied to every house eligible in this analysis. The largest emissions reductions occur from the wall and window retrofit packages when applied to the existing housing stock, without work planned on the house. These range from 74 to 101 MMT. However, the 1" insulation alone results in 57 MMT of avoided long-run emissions when done without work planned on the house and 50 MMT if done at the time of re-siding, showing 78%–80% of the emissions reduction potential from 2" insulation. 2" insulation has results of 71 MMT of avoided long-run emissions when done without work planned on the house and 64 MMT if done at the time of re-siding. Figure A-5, in the appendix, presents the same figure with all four sets of emissions factors used in the analysis to reflect the uncertainty in the future of the electric grid.

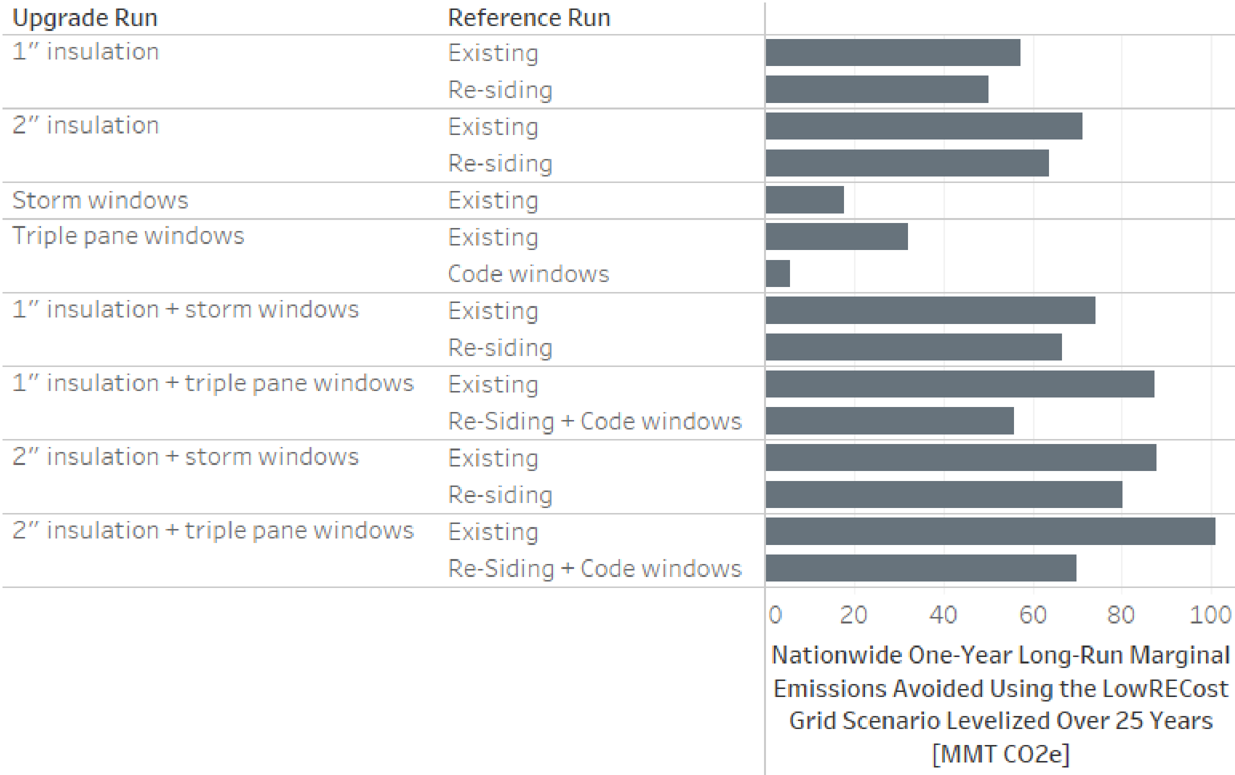

Figure 6. Total one-year nationwide carbon emissions reduction if every house represented in the analysis were to have the specified retrofit case implemented. The results are shown using the carbon emissions factors developed using the LowRECost grid scenario with levelization over 25 years. Figure A-5 shows the same results four different sets of emissions factors, as described in Section 2.8, to reflect the uncertainty in the future of the electric grid.

3.3 Energy Consumption

Average changes in total annual site energy consumption across all fuels are presented in Figure 7 (all cases, MMBtu/year) and Figure 8 (cases with reference of existing stock only, in percent savings from existing stock). Figures that include these values alongside the standard deviation (σ), which indicates the distribution across the diversity of housing stock characteristics (e.g., thermostat setpoints), are available in Appendix A. Averages are shown rather than medians to allow the values to be aggregated to calculate total energy savings across a population of houses. These values are computed across all houses to which any part of the upgrade model run was applied.[38] Houses to which no part of a given upgrade model run are applied are not included in the calculations for that specific upgrade model run. Positive values are energy *savings*; the few instances of negative values from individual models, as seen in the histograms in Figure 9, are increases in energy consumption. In Figure 7, darker background colors indicate greater average energy savings. These energy consumption and energy savings values include all four fuel types considered in the analysis: electricity, natural gas, propane, and fuel oil.

[38] For example, a house with R-19 insulation and single-pane windows would have the window upgrade portion of an upgrade package applied, but not the insulation portion.

Building America Climate Zone	Vintage	1″ insulation: Existing	1″ insulation: Re-siding	2″ insulation: Existing	2″ insulation: Re-siding	Storm windows: Existing	Triple pane windows: Existing	Triple pane windows: Code windows	1″ insulation + storm windows: Existing	1″ insulation + storm windows: Re-siding	1″ insulation + triple pane windows: Existing	1″ insulation + triple pane windows: Re-Siding + Code windows	2″ insulation + storm windows: Existing	2″ insulation + storm windows: Re-siding	2″ insulation + triple pane windows: Existing	2″ insulation + triple pane windows: Re-Siding + Code windows
Cold & Very Cold	Before 1950	37.0	32.2	45.4	40.6	17.1	30.2	4.2	41.9	37.7	48.4	31.7	49.5	45.2	56.0	39.3
	1950-1969	29.8	26.4	36.7	33.3	14.1	25.2	3.5	32.9	29.8	38.2	25.1	38.9	35.9	44.2	31.1
	1970-1989	15.9	10.1	20.1	14.3	13.6	24.8	4.1	19.6	14.5	24.3	10.8	23.3	18.2	28.0	14.6
Mixed-Humid	Before 1950	29.1	26.0	35.7	32.6	12.5	22.8	3.8	33.4	30.6	38.8	26.4	39.5	36.7	44.9	32.5
	1950-1969	24.4	23.0	30.2	28.8	10.1	18.7	3.3	27.4	26.1	31.7	23.0	32.6	31.4	37.0	28.2
	1970-1989	13.2	10.3	16.6	13.7	8.9	16.5	3.6	16.3	13.7	20.2	11.2	19.3	16.8	23.2	14.3
Marine	Before 1950	16.4	17.8	20.9	22.3	6.0	10.5	1.8	19.2	20.7	21.5	18.7	23.7	25.1	25.8	23.1
	1950-1969	13.9	14.7	17.6	18.4	4.3	7.8	1.5	15.9	16.7	17.7	15.4	19.6	20.4	21.3	19.0
	1970-1989	9.1	8.4	11.8	11.1	4.3	8.0	1.7	11.0	10.3	12.8	9.2	13.7	12.9	15.4	11.8
Hot-Dry & Mixed-Dry	Before 1950	10.6	11.8	13.6	14.9	3.9	6.8	1.6	12.5	13.7	14.1	12.4	15.4	16.6	16.9	15.3
	1950-1969	11.6	11.8	14.6	14.8	3.8	6.8	1.8	13.4	13.6	15.3	12.4	16.2	16.4	18.0	15.1
	1970-1989	7.8	6.6	9.8	8.6	4.1	7.7	2.2	10.1	9.0	12.5	7.7	12.0	10.8	14.3	9.5
Hot-Humid	Before 1950	12.9	12.1	16.2	15.4	6.0	10.9	2.3	15.6	14.9	19.1	12.4	18.3	17.6	21.9	15.1
	1950-1969	10.6	10.4	13.3	13.1	5.0	9.2	1.8	12.2	12.0	15.5	9.7	14.3	14.1	17.5	11.7
	1970-1989	6.3	5.0	7.8	6.5	5.2	9.5	1.9	8.6	7.7	12.1	5.1	9.7	8.7	13.2	6.2

Upgrade Run / Reference Run

Figure 7. Average (mean) of annual site energy savings (MMBtu/year) for each retrofit case, aggregated by climate zone and vintage range

Figure 7 shows greatest average energy savings in the Cold & Very Cold and Mixed-Humid climate zones. Due to the structure of ResStock, this locational variation includes both the impacts of different weather and the differences in the housing stock in each climate zone. The figures also show greater energy savings for older homes. The case of the fourth package (triple-pane, 2” insulation, and re-siding) in reference to the existing building stock consistently shows the greatest average energy savings, though not by a wide margin.

Figure 8 shows each model run’s average annual energy savings across the four included fuels as a percent of the baseline/existing energy consumption, for each upgrade scenario relative to the existing stock (baseline), for homes that received any changes as part of that run. Some of the packages show over 25% energy savings on average. The largest energy savings by percent is in the older vintages and the colder climate zones.

Building America Climate Zone	Vintage	Upgrade Run / Reference Run: 1″ insulation / Existing	2″ insulation / Existing	Storm windows / Existing	Triple pane windows / Existing	1″ insulation + storm windows / Existing	1″ insulation + triple pane windows / Existing	2″ insulation + storm windows / Existing	2″ insulation + triple pane windows / Existing
Cold & Very Cold	Before 1950	19%	23%	8%	15%	21%	23%	26%	28%
	1950-1969	17%	21%	8%	13%	19%	20%	23%	24%
	1970-1989	10%	13%	8%	15%	11%	13%	14%	15%
Mixed-Humid	Before 1950	18%	22%	8%	14%	21%	23%	25%	27%
	1950-1969	17%	21%	7%	12%	19%	21%	23%	25%
	1970-1989	10%	12%	7%	13%	12%	15%	15%	17%
Marine	Before 1950	15%	20%	5%	9%	17%	19%	22%	24%
	1950-1969	14%	18%	4%	7%	16%	17%	20%	22%
	1970-1989	9%	12%	4%	8%	11%	12%	14%	15%
Hot-Dry & Mixed-Dry	Before 1950	12%	16%	4%	7%	14%	16%	18%	19%
	1950-1969	13%	17%	4%	7%	15%	17%	19%	21%
	1970-1989	8%	10%	4%	8%	11%	13%	13%	15%
Hot-Humid	Before 1950	13%	16%	6%	11%	16%	19%	19%	22%
	1950-1969	12%	15%	5%	10%	13%	16%	16%	19%
	1970-1989	7%	8%	6%	11%	9%	13%	10%	14%

Figure 8. Average (mean) of percent site energy savings for each upgrade scenario compared to the existing building stock (baseline reference scenario), aggregated by climate zone and vintage range

The site energy savings histograms in Figure 9 show some of the story behind these averages. These histograms have an overflow bin for values of 100 MMBtu/year savings and more, an underflow bin for values of -40 MMBtu/year savings and less (energy consumption increases of 40 MMBtu/year or more), and a bin size of 2 MMBtu/year. We see many homes with savings of under 50 MMBtu/yr, a few homes with negative savings, and long tails of high energy savings as demonstrated by the high house counts in some of the 100+ MMBtu/yr bins. The distributions in cases comparing an upgrade to a non-baseline reference upgrade show lower peaks and fewer homes with very high savings compared to the distributions for the same upgrade compared to the existing stock.

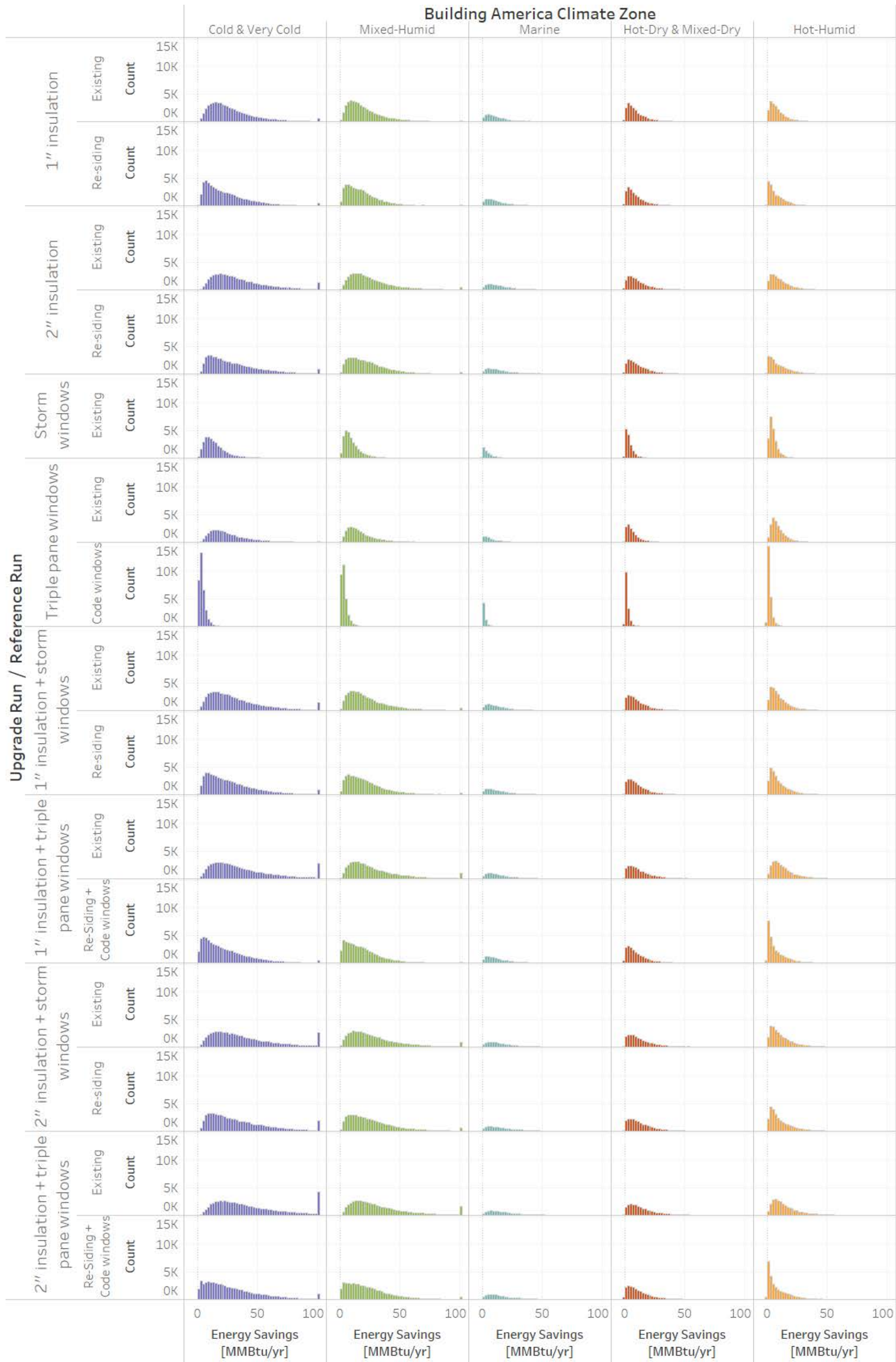

Figure 9. Distributions of annual site energy savings (MMBtu/year) for all retrofit cases in the analysis, separated by climate zone. The histograms have a bin size of 2 MMBtu/year, an overflow bin for values 100 MMBtu/year and over, and an underflow bin for values below -40 MMBtu/year. Negative values indicate an increase in energy use.

3.4 Energy Bill Savings

Annual energy bill savings are presented as averages in Figure 10. Averages are used rather than medians to allow the values to be aggregated to calculate total bill savings across a population. A version of this figure that presents the average alongside the standard deviation (σ) is available in Appendix A. Averages are over only those homes to which some portion of the upgrade applied. If a home received some portion of the upgrade but not of the reference case, the existing stock is used as the reference case for that home (e.g., for the 1" insulation + storm windows upgrade, a home eligible for the window upgrades but not the wall upgrades would not be eligible for the re-siding reference component and would have its upgrade results compared to the existing stock, since it would not have been included in the relevant reference run). The darker the background color, the greater the annual bill savings. Annual bill savings are negative (i.e., increase) in some cases where annual energy savings are negative.

		Upgrade Run / Reference Run														
		1″ insulation		2″ insulation		Storm windows	Triple pane windows		1″ insulation + storm windows		1″ insulation + triple pane windows		2″ insulation + storm windows		2″ insulation + triple pane windows	
Building America Climate Zone	Vintage	Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows
Cold & Very Cold	Before 1950	$578	$500	$708	$630	$261	$462	$63	$652	$582	$751	$489	$770	$699	$869	$607
	1950-1969	$459	$404	$565	$510	$205	$367	$50	$500	$452	$578	$382	$593	$545	$670	$474
	1970-1989	$275	$174	$346	$245	$235	$429	$69	$340	$250	$419	$185	$403	$313	$483	$248
Mixed-Humid	Before 1950	$509	$454	$624	$569	$217	$392	$64	$584	$533	$676	$459	$691	$640	$782	$565
	1950-1969	$443	$413	$547	$517	$189	$345	$58	$500	$474	$580	$411	$595	$568	$675	$505
	1970-1989	$287	$222	$359	$295	$199	$364	$75	$357	$300	$442	$240	$422	$365	$507	$305
Marine	Before 1950	$282	$307	$359	$384	$105	$185	$32	$331	$356	$371	$321	$407	$432	$446	$397
	1950-1969	$247	$258	$312	$323	$79	$145	$26	$285	$296	$317	$269	$349	$359	$380	$332
	1970-1989	$166	$154	$214	$202	$84	$156	$31	$203	$191	$238	$167	$251	$239	$285	$214
Hot-Dry & Mixed-Dry	Before 1950	$229	$242	$292	$305	$89	$158	$29	$275	$287	$315	$252	$334	$347	$373	$310
	1950-1969	$251	$243	$313	$305	$93	$169	$31	$300	$292	$346	$253	$357	$349	$402	$309
	1970-1989	$188	$155	$233	$201	$124	$222	$45	$263	$232	$330	$178	$305	$275	$371	$220
Hot-Humid	Before 1950	$312	$280	$387	$355	$146	$267	$49	$377	$349	$466	$282	$440	$413	$529	$345
	1950-1969	$256	$231	$316	$292	$125	$230	$39	$298	$280	$381	$215	$345	$326	$427	$261
	1970-1989	$171	$127	$211	$166	$144	$263	$48	$237	$206	$334	$130	$265	$234	$361	$157

Figure 10. Average (mean) annual bill savings ($/year) for each retrofit case in the analysis, aggregated by climate zone and vintage range. Older vintages and colder climates see greater bill savings.

These figures show the greatest average energy bill savings occur in the Cold & Very Cold and Mixed-Humid climate zones; these are the same areas that showed the greatest energy savings. However, the Hot-Humid climate zone shows high average energy bill savings as well, much higher than would be expected from its energy savings relative to the other climate zones. This is due primarily to the type of energy being saved and its relative cost—many more homes heat with electricity in the Hot-Humid climate zone than in most of the other climate zones.

As in the Energy Consumption section, the histograms in Figure 11 show some of the story behind these averages. These histograms use an overflow bin for homes with one-year energy bill savings of $1,500 or more, an underflow bin for homes with one-year energy bill increases of $400 or more (savings of -$400 or less), and a bin size of $50.

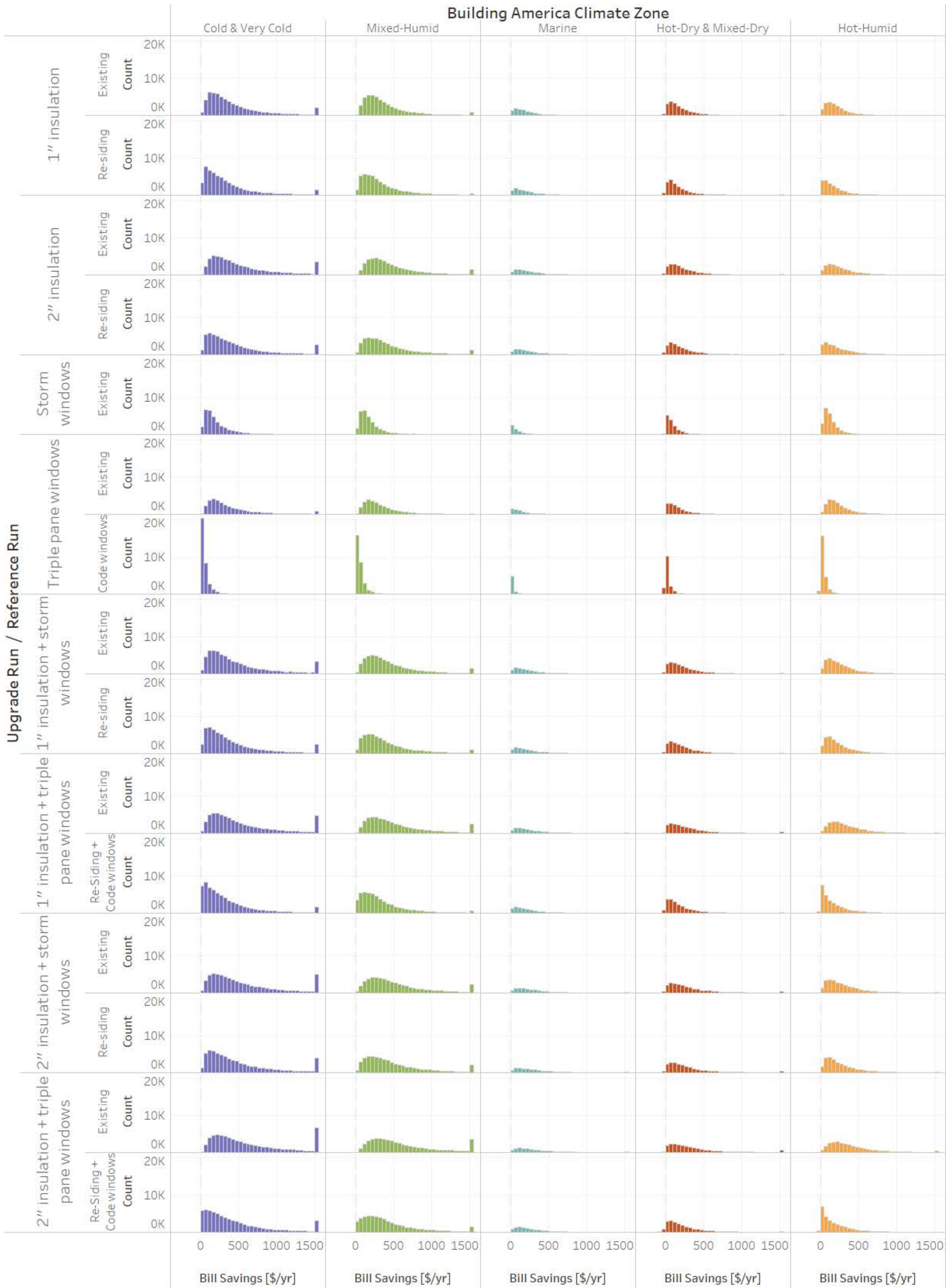

Figure 11. Distributions of annual bill savings ($/year) for each retrofit case in the analysis, separated by climate zone. The histograms use a bin size of $50, an overflow bin for values $1,500 or higher, and an underflow bin for values -$400 or below.

As seen in Figure 11, some of the distributions in the Cold & Very Cold and Mixed-Humid climate zones peak in the $200–$300 per year range of energy bill savings. There is also a very long high tail, as evidenced by the height of the $1,500+ bin. The peaks of the distributions are at lower energy bill savings in the warmer climate zones.

3.5 Simple Payback Period

The simple payback periods (SPP) results span a very wide range that is not meaningfully captured by means, medians, or other summary statistics. This metric is also extremely sensitive to outliers.[39]

Therefore, Figure 12 shows the percentage of homes whose SPP was less than 30 years (but not negative) for each climate zone and vintage range combination. Darker colors are used for higher percentages of homes having SPP in the 0-30 year range.

		Upgrade Run / Reference Run														
		1″ insulation		2″ insulation		Storm windows	Triple pane windows		1″ insulation + storm windows		1″ insulation + triple pane windows		2″ insulation + storm windows		2″ insulation + triple pane windows	
Building America Climate Zone	Vintage	Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows
Cold & Very Cold	Before 1950	56%	77%	62%	78%	46%	29%	14%	68%	79%	58%	78%	73%	79%	63%	79%
	1950-1969	43%	69%	49%	70%	41%	25%	11%	57%	71%	48%	70%	62%	72%	53%	71%
	1970-1989	19%	47%	23%	50%	33%	22%	14%	32%	52%	28%	48%	36%	54%	31%	50%
Mixed-Humid	Before 1950	55%	86%	62%	86%	50%	28%	10%	66%	86%	55%	86%	72%	86%	61%	86%
	1950-1969	46%	84%	54%	84%	48%	28%	10%	59%	84%	49%	85%	66%	84%	56%	85%
	1970-1989	17%	58%	22%	60%	47%	27%	13%	33%	65%	27%	55%	37%	66%	30%	57%
Marine	Before 1950	27%	89%	33%	88%	30%	9%	4%	30%	84%	23%	83%	36%	84%	29%	83%
	1950-1969	20%	84%	26%	82%	26%	8%	4%	22%	78%	18%	76%	28%	77%	22%	75%
	1970-1989	9%	50%	13%	51%	25%	7%	5%	12%	51%	9%	45%	15%	51%	12%	47%
Hot-Dry & Mixed-Dry	Before 1950	16%	74%	22%	72%	29%	8%	6%	20%	67%	15%	63%	25%	66%	19%	62%
	1950-1969	17%	73%	22%	70%	36%	10%	6%	23%	68%	16%	64%	28%	67%	20%	63%
	1970-1989	8%	43%	11%	42%	48%	16%	10%	16%	52%	11%	36%	19%	50%	13%	37%
Hot-Humid	Before 1950	26%	76%	33%	75%	64%	24%	4%	45%	75%	28%	61%	51%	75%	34%	64%
	1950-1969	14%	62%	19%	61%	65%	23%	3%	38%	63%	21%	48%	42%	62%	25%	49%
	1970-1989	3%	27%	5%	27%	68%	25%	5%	31%	39%	14%	22%	32%	37%	15%	23%

Figure 12. Percent of eligible homes for each retrofit case and reference scenario in each climate zone and vintage range where the SPP is positive and less than 30 years. Unlike energy savings and bill savings, the highest portions of eligible houses meeting this metric for the packages are not in the Cold & Very Cold climate zone, but in the Mixed-Humid and Marine climate zones.

Figure 13 shows histograms of SPP. These histograms use an overflow bin for values of 75 years or more, an underflow bin for values below 0 years, and a bin size of 3 years.

[39] For example, in one of our early test runs, a relatively typical example house in our modeling results saw an 8.2 MMBtu/yr annual energy savings for the insulation-only upgrade and a $260 annual bill savings, which led to a simple payback period of 7.2 years. Meanwhile, looking at the same upgrade, a single house in Arizona in the Hot-Dry climate with no air conditioning and a low heating setpoint (60°F) showed very nearly no change in energy consumption—just a -1.4 x 10^{-8} MMBtu/yr increase and an accordingly small change in utility bills of a tiny fraction of a penny (-$1.23x$10^{-7}$). This house is clearly not a good candidate for this upgrade, and there are not too many like it in the data set, but it does meet the requirements laid out by the team and its SPP greatly distorts some aggregations.

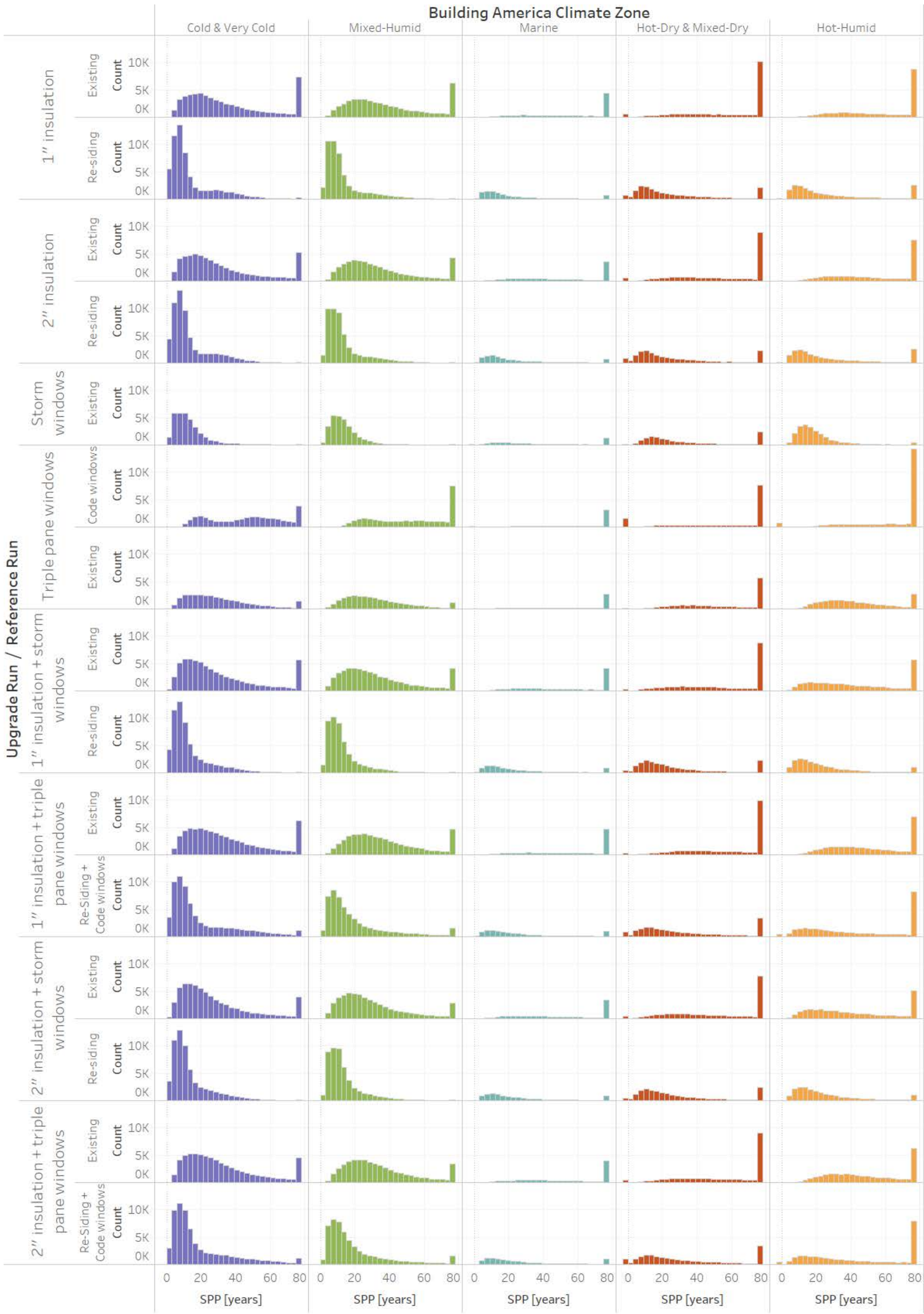

Figure 13. Distributions of simple payback period (years) for each retrofit case included in the analysis, separated by climate zone. The histograms have a bin size of 3 years with an overflow bin for 75 years and above, and an underflow bin for 0 years and below.

Figure 13 shows how the SPPs are distributed in each climate zone. Although every distribution of upgrade package SPP shown peaks below 20 years, the tails on many of the distributions are very, very long. Every package case in the Hot-Dry and Mix-Dry climate zone, compared to the existing building stock, has at least 5,000 sample houses (about 22%) in the 50+ years bin, which may be explained by homes without air conditioning or with very low heating setpoints. The cases comparing packages to planned work rather than existing building stock have lower peak values and fewer homes in the overflow bins, reflecting the economic advantages to implementing energy upgrades when work was already planned on a house.

3.6 Net Present Value

Net present value (NPV) is a common metric for determining cost-effectiveness of energy efficiency measures from a homeowner’s perspective. A positive NPV suggests that a measure would be a good investment for homeowners planning to own the home for the lifetime of the measure (or that the financing can be passed on to a future owner).

Figure 14 shows the percent of eligible homes in each climate zone and vintage range where the upgrade has a positive NPV. This table is one of the key results of this analysis. It shows storm windows with consistently higher rates of positive NPV than triple-pane windows when compared to the existing housing stock. It shows 1” and 2” insulation with very similar results across climate zones and vintages within the analysis—with consistently above 60% seeing a positive NPV in all pre-1970 homes when compared to the re-siding reference case, in every climate zone. For the wall-window packages, in the pre-1970 vintages in the Mixed-Humid and Marine climate zones, all of the upgrade scenarios see 83% or more homes with a positive NPV when compared to the re-siding + code windows reference case.

		Upgrade Run / Reference Run														
		1” insulation		2” insulation		Storm windows	Triple pane windows		1” insulation + storm windows		1” insulation + triple pane windows		2” insulation + storm windows		2” insulation + triple pane windows	
Building America Climate Zone	Vintage	Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows
Cold & Very Cold	Before 1950	41%	91%	47%	91%	81%	33%	12%	48%	92%	37%	80%	53%	92%	41%	80%
	1950-1969	32%	86%	38%	86%	80%	30%	10%	41%	87%	30%	73%	45%	86%	34%	73%
	1970-1989	11%	42%	14%	44%	77%	35%	18%	23%	48%	16%	37%	25%	48%	19%	39%
Mixed-Humid	Before 1950	31%	99%	38%	98%	77%	26%	3%	38%	96%	28%	81%	44%	96%	33%	82%
	1950-1969	24%	98%	30%	98%	78%	25%	4%	32%	96%	23%	80%	38%	96%	27%	81%
	1970-1989	7%	48%	10%	50%	78%	24%	6%	17%	55%	10%	38%	20%	55%	12%	40%
Marine	Before 1950	11%	79%	15%	77%	32%	6%	0%	13%	71%	9%	66%	16%	70%	12%	65%
	1950-1969	7%	71%	10%	67%	27%	4%	1%	9%	61%	6%	57%	11%	60%	8%	56%
	1970-1989	3%	33%	4%	32%	27%	4%	1%	4%	31%	3%	27%	5%	30%	4%	27%
Hot-Dry & Mixed-Dry	Before 1950	6%	60%	10%	57%	27%	4%	3%	8%	51%	6%	44%	11%	50%	8%	43%
	1950-1969	6%	62%	9%	59%	34%	4%	3%	9%	55%	6%	45%	11%	53%	7%	45%
	1970-1989	3%	29%	4%	29%	47%	6%	5%	7%	33%	3%	22%	8%	31%	4%	22%
Hot-Humid	Before 1950	10%	80%	14%	77%	58%	9%	0%	20%	75%	8%	43%	23%	73%	10%	44%
	1950-1969	4%	69%	6%	66%	55%	7%	0%	18%	66%	5%	33%	20%	64%	6%	34%
	1970-1989	1%	26%	1%	25%	61%	8%	1%	20%	32%	3%	11%	20%	30%	3%	12%

Figure 14. Percent of eligible homes in each climate zone and vintage range with a positive NPV for each retrofit case in the analysis

Figure 15 shows how the net present values are distributed in each climate zone.

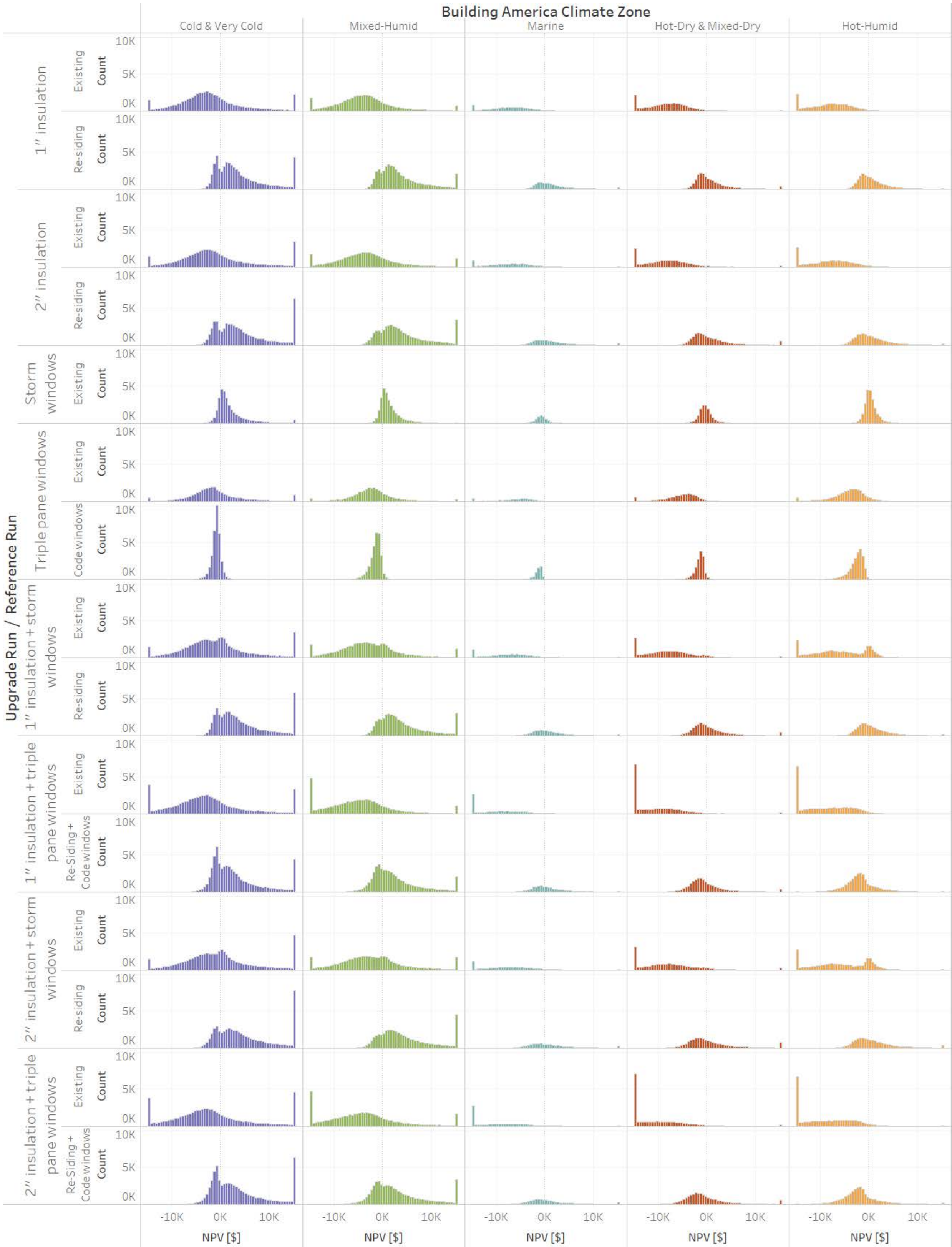

Figure 15. Distributions of NPV ($) for each retrofit case and reference scenario, separated by climate zone. The histograms use a bin size of $1,000, an overflow bin for $15,000 and higher, and an underflow bin for -$15,000 and lower.

Figure 16 shows the percent of homes with positive NPVs in each state for each retrofit case with a stand-alone insulation upgrade scenario. Figure 17 shows the same for retrofit cases with a stand-alone window upgrade scenario.

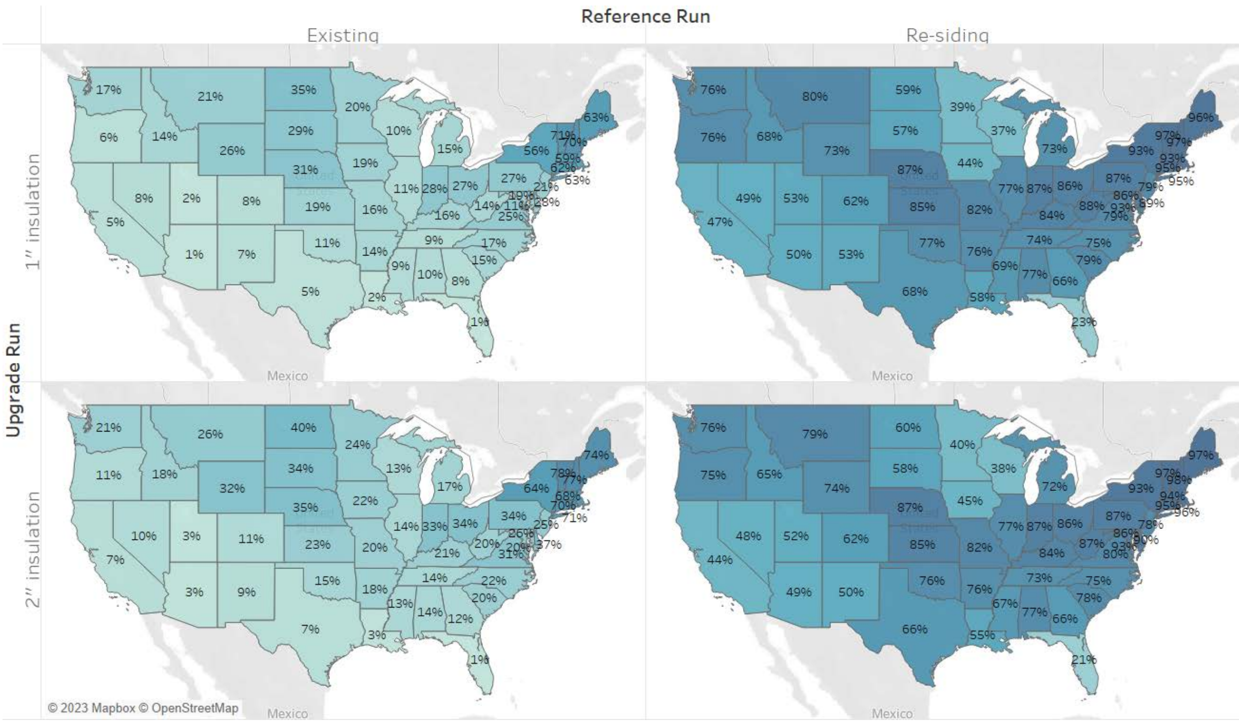

Figure 16. Percent of eligible homes in each state where the upgrade has a positive NPV, for each insulation-only retrofit case in the analysis. Results reflect the variation between states in housing stock characteristics, climate, resident behavior (e.g., thermostat setpoints), and energy prices. A higher percentage of homes have positive NPVs when exterior insulation is installed at the time of re-siding, but in some areas of the country even 1" insulation done without planned work shows a positive NPV in a majority of eligible homes—this value is near or above 60% throughout New England.

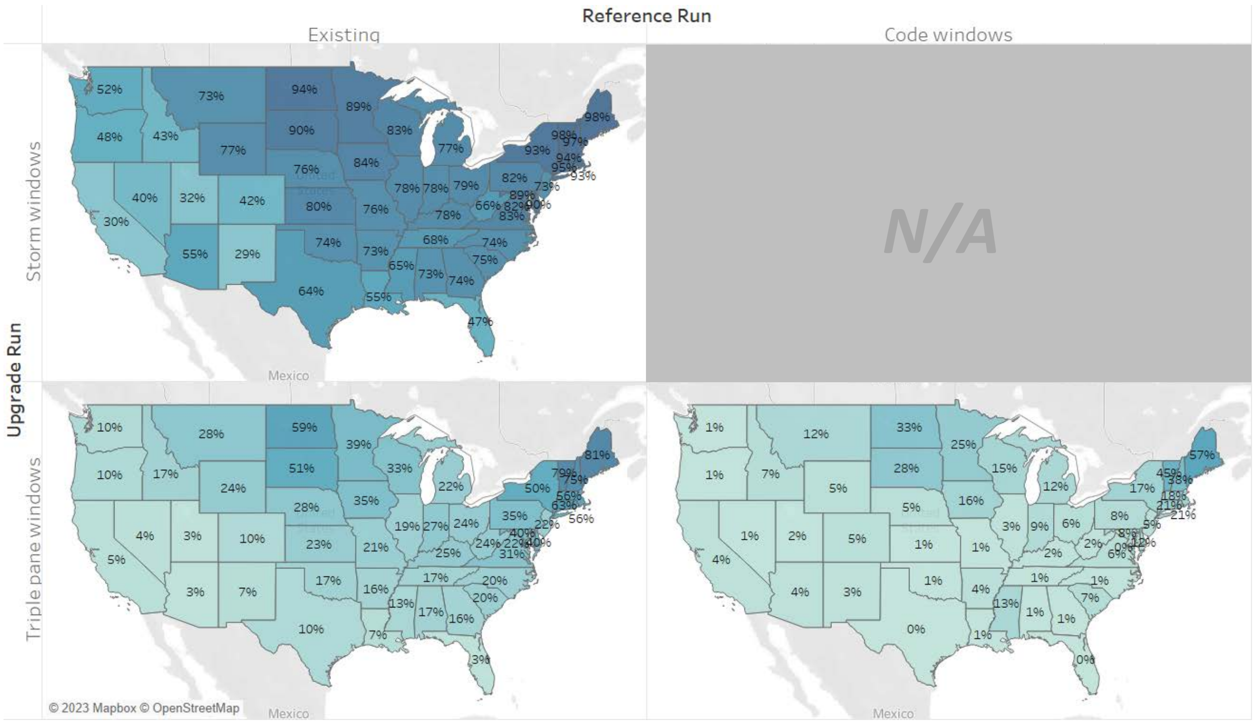

Figure 17. Percent of eligible homes in each state where the upgrade has a positive NPV, for each windows-only retrofit case in the analysis. Results reflect the variation between states in housing stock characteristics, climate, resident behavior (e.g., thermostat setpoints), and energy prices. Exterior low-E storm windows show positive NPV in over half of eligible homes in most areas of the country other than the Southwest. Triple-pane windows installed without planned work show positive NPV in over half of eligible homes in New England, New York, and the Dakotas. Triple-paned windows installed at the time of planned window replacement show lower portions of homes with positive NPVs, but still over 25% of homes show positive NPV in New England and parts the upper Midwest.

3.6.1 Accounting for Increase in Home Resale Value

Siding and window upgrades typically increase the resale value of a home, recouping 67%–68% of the job cost (national average), as documented in Remodeling Magazine's Cost vs. Value report.[40] We therefore considered an alternate NPV calculation for triple-pane windows that used only 33% of the net capital cost. The resale value would occur at some unknown time in the future when the home is sold; however, we did not discount the increase in resale value, so this alternate NPV should be considered a maximum value (i.e., if the home is sold immediately after the upgrade).

Figure 18 shows that this has a significant impact on NPV calculations for window upgrades. With this alternate NPV calculation, the median NPV for the triple-pane window upgrade scenario relative to the code-minimum window reference scenario is positive for the Cold & Very Cold and Mixed-Humid climate zones across all original window types included in this analysis. For the triple-pane window upgrade scenario relative to the existing housing stock, the median NPV is positive across the Cold & Very Cold, Mixed-Humid, and Hot-Humid climate zones, as well as for houses in the Hot-Dry/Mixed-Dry climate zone with baseline single-pane metal framed windows.

[40] Remodeling by JLC. 2021. "2021 Cost vs Value Report." https://www.remodeling.hw.net/cost-vs-value/2021/

		Upgrade Run / Reference Run			
		Triple pane windows			
		Median NPV (using net capital cost) [$]		Median NPV accounting for increased home value (using only 33% of net capital cost) [$]	
Building America Climate Zone	Baseline Window	Existing	Code windows	Existing	Code windows
Cold & Very Cold	Single, Clear, Metal	-786	-807	4,061	120
	Single, Clear, Non-metal	-1,296	-805	3,276	102
	Single, Clear, Metal, Exterior Clear Storm	-1,457	-723	2,775	140
	Single, Clear, Non-metal, Exterior Clear Storm	-2,678	-824	1,664	96
	Double, Clear, Metal, Air	-3,262	-830	1,207	108
Mixed-Humid	Single, Clear, Metal	-1,385	-1,333	3,509	40
	Single, Clear, Non-metal	-1,952	-1,288	2,804	16
	Single, Clear, Metal, Exterior Clear Storm	-2,549	-1,309	2,238	53
	Single, Clear, Non-metal, Exterior Clear Storm	-3,003	-1,271	1,673	33
	Double, Clear, Metal, Air	-3,591	-1,277	1,133	74
Marine	Single, Clear, Metal	-5,212	-1,223	-362	-174
	Single, Clear, Non-metal	-5,004	-1,166	-160	-135
	Single, Clear, Metal, Exterior Clear Storm	-5,099	-1,138	-674	-192
	Single, Clear, Non-metal, Exterior Clear Storm	-5,651	-1,145	-1,061	-160
	Double, Clear, Metal, Air	-6,135	-1,194	-1,020	-145
Hot-Dry & Mixed-Dry	Single, Clear, Metal	-4,172	-1,420	742	-204
	Single, Clear, Non-metal	-4,863	-1,354	-167	-225
	Single, Clear, Metal, Exterior Clear Storm	-5,531	-1,453	-574	-241
	Single, Clear, Non-metal, Exterior Clear Storm	-5,441	-1,312	-700	-236
	Double, Clear, Metal, Air	-5,424	-1,385	-288	-195
Hot-Humid	Single, Clear, Metal	-3,217	-2,380	1,728	-416
	Single, Clear, Non-metal	-3,738	-2,278	1,109	-376
	Single, Clear, Metal, Exterior Clear Storm	-4,341	-2,295	554	-380
	Single, Clear, Non-metal, Exterior Clear Storm	-4,500	-2,177	212	-308
	Double, Clear, Metal, Air	-4,783	-2,288	330	-339

Figure 18. Median NPV for the triple-pane stand-alone upgrade scenario retrofit cases, aggregated by climate zone and baseline window type. The NPV values are presented using both the standard calculation (using the net capital cost) and with an alternate calculation that accounts for the fact that window upgrades typically recoup 67% of their cost at resale.

3.7 Emissions

Figure A-6 presents the emissions results in terms of average one-year per-house avoided carbon emissions for each of the retrofit cases in this analysis, aggregated by climate zone and vintage. Emissions results are shown for the LowRECost 25-year levelization emissions factors. Figure A-6 presents the same results using all four sets of emissions factors included in the analysis.

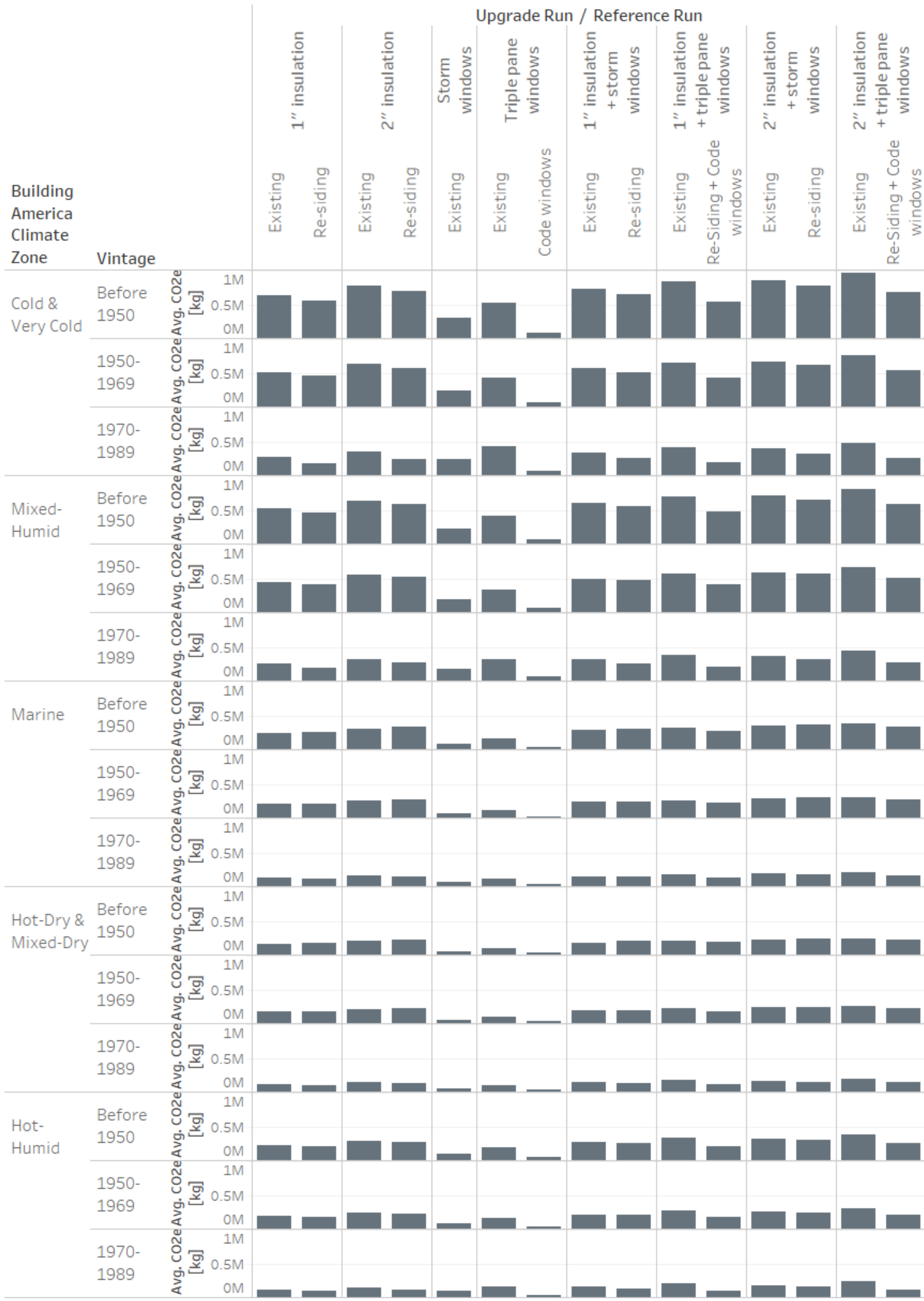

Figure 19. Average per-house avoided carbon emissions (kg CO_{2e}/yr) for one year aggregated by climate zone and vintage range, for each retrofit case in the analysis, using the LowRECost emissions scenario with 25 year levelization period.

Figure 19 shows the 2” insulation upgrade scenario yields consistently greater avoided carbon emissions than the 1” insulation, by about 25%. The triple-pane window upgrade scenario yields consistently greater avoided carbon emissions than the storm windows when compared to the existing house reference scenario. The 1” insulation + triple-pane window upgrade scenario has comparable results (compared to the existing housing stock) to the 2” insulation + storm windows upgrade scenario.

4 Conclusions

The analysis presented here used ResStock simulations to produce distributions of site energy savings, bill savings, SPP, NPV, and avoided CO_{2e} emissions for wall insulation and window upgrade scenarios applied across the pre-1990 single-family detached housing stock in the contiguous United States. One conclusion from this work is that the cost-effectiveness of these upgrades can vary widely; the median NPV is sometimes positive and sometimes negative, but in many cases, the interquartile range spans both negative and positive NPV values. This variation is due to diversity in housing stock characteristics and occupant behavior, climate variations within each climate zone, and electricity and fuel price differences between states. One limitation of this work is that we used single values for the cost of each upgrade per square foot of exterior wall or window—no variation based on location or other factors. Including such variation may further increase the variability in NPV. We also used statewide average utility rates. Another caveat is that the NPV calculations are sensitive to the assumed 3.4% real discount rate and 30-year analysis period, and the NPV calculations did not include a residual value for capital improvements at the end of the 30-year analysis period.

With the variation in NPV in mind, there are several conclusions that can be made (all drawn from Figure 14 unless otherwise specified):

- In Cold and Mixed-Humid climate homes built before 1970, adding insulation at time of re-siding is almost always cost-effective—the NPV is positive for at least 85% of eligible homes (i.e., about 15 million homes have positive NPV).
- In homes built before 1970 in warmer climates, the NPV of adding insulation at time of re-siding is positive for a majority—at least 55%—of eligible homes (about 4 million).
- When 1” insulation at time of re-siding is bundled with low-E storm window upgrades, the packages are cost-effective in at least 85% of eligible homes built before 1970 in Cold and Mixed-Humid climates (about 17 million).
- When 1” insulation at time of re-siding is bundled with triple-pane window upgrades and also done at the time of planned window replacement, the packages are cost-effective in at least 70% of eligible homes built before 1970 in Cold and Mixed-Humid climates (about 14 million).
- Window upgrades alone are less likely to be cost-effective than the insulation upgrades alone. Window upgrades show a positive NPV in:
    - About 80% of eligible homes (12.3 million) in Cold and Mixed-Humid climates for low-E storms
    - About 25% of eligible homes (3.8 million) in Cold and Mixed-Humid climates for triple-pane windows without work planned on the house and about 13% (2.0 million) in Cold climates at the time of window replacement.

Our analysis uniquely included an alternate NPV calculation for window replacements that accounted for the expected increase in home resale value:

- As shown in Figure 17, including the increase in home resale value due to window replacement in the NPV calculation (undiscounted) changes these values dramatically, with a positive NPV in:

  - About 99% of eligible homes (15.2 million) in Cold and Mixed-Humid climates for low-E storms.
  - About 90% of eligible homes (13.8 million) in Cold and Mixed-Humid climates for triple-pane windows compared to existing building stock (no work planned).
  - Over 50% of eligible homes (7.7 million) in Cold and Mixed-Humid climates for triple-pane windows compared to planned replacement with code-minimum windows.
  - About 96% of eligible homes (5.4 million) in Hot-Humid climates for adding low-E storms to non-low-E single- or double-pane windows without storms.
  - About 75% of eligible homes (4.2 million) in Hot-Humid climates for triple-pane windows replacing existing windows.

We make several final conclusions by comparing the cost-effectiveness of different measures and packages:

- Across all climate zones, low-E storm windows save less energy per household than the other stand-alone measures (1" insulation, 2" insulation, and triple-pane windows) when all are considered without planned work on the house. 1" insulation has better cost-effectiveness than triple-pane windows with only a few exceptions when also accounting for the increase in home resale value from triple-pane windows. This suggests that if one had to focus on pairing only one of the measures with planned house updates, then it would make sense to focus on 1" insulation, though there might be other reasons, such as thermal comfort or lead abatement, to promote window upgrades as well.
- Based on our cost and energy rate input assumptions, there is little difference in the cost-effectiveness of 1" insulation and 2" insulation (whether or not they are packaged with window upgrades). Increasing from 1" to 2" increases annual bill savings by $50–$200 (Figure 10) and increases the carbon emissions reduction about 25%, but there is little difference in NPV, and practical challenges may make 2" insulation retrofits less desirable than 1" or 1.5".

These conclusions can help inform retrofit recommendations and market transformation efforts in the re-siding and window replacement markets.

Appendix A. Additional Figures

Figure A-1 shows the average *and standard deviation (σ)* of site energy savings for all upgrade scenarios with their appropriate reference scenarios.

		Upgrade Run / Reference Run														
		1″ insulation		2″ insulation		Storm windows	Triple pane windows		1″ insulation + storm windows		1″ insulation + triple pane windows		2″ insulation + storm windows		2″ insulation + triple pane windows	
Building America Climate Zone	Vintage	Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows
Cold & Very Cold	Before 1950	37.0 (σ22.7)	32.2 (σ20.5)	45.4 (σ27.1)	40.6 (σ25.4)	17.1 (σ11.6)	30.2 (σ20.3)	4.2 (σ3.1)	41.9 (σ28.3)	37.7 (σ25.4)	48.4 (σ33.5)	31.7 (σ22.5)	49.5 (σ32.8)	45.2 (σ30.3)	56.0 (σ37.6)	39.3 (σ27.8)
	1950-1969	29.8 (σ18.2)	26.4 (σ17.3)	36.7 (σ21.9)	33.3 (σ21.3)	14.1 (σ9.5)	25.2 (σ16.7)	3.5 (σ2.6)	32.9 (σ22.4)	29.8 (σ20.6)	38.2 (σ26.4)	25.1 (σ18.8)	38.9 (σ26.1)	35.9 (σ24.7)	44.2 (σ29.7)	31.1 (σ23.2)
	1970-1989	15.9 (σ10.6)	10.1 (σ7.5)	20.1 (σ12.7)	14.3 (σ9.9)	13.6 (σ9.5)	24.8 (σ16.8)	4.1 (σ3.1)	19.6 (σ14.4)	14.5 (σ11.6)	24.3 (σ19.6)	10.8 (σ8.4)	23.3 (σ16.3)	18.2 (σ13.5)	28.0 (σ21.0)	14.6 (σ11.0)
Mixed-Humid	Before 1950	29.1 (σ19.6)	26.0 (σ16.1)	35.7 (σ23.2)	32.6 (σ20.1)	12.5 (σ9.2)	22.8 (σ17.0)	3.8 (σ3.0)	33.4 (σ24.3)	30.6 (σ20.8)	38.8 (σ29.2)	26.4 (σ18.1)	39.5 (σ28.0)	36.7 (σ24.7)	44.9 (σ32.6)	32.5 (σ22.3)
	1950-1969	24.4 (σ15.7)	23.0 (σ13.8)	30.2 (σ18.8)	28.8 (σ17.2)	10.1 (σ7.4)	18.7 (σ13.7)	3.3 (σ2.6)	27.4 (σ19.3)	26.1 (σ17.4)	31.7 (σ23.1)	23.0 (σ15.5)	32.6 (σ22.5)	31.4 (σ20.8)	37.0 (σ26.0)	28.2 (σ19.2)
	1970-1989	13.2 (σ10.1)	10.3 (σ9.9)	16.6 (σ12.3)	13.7 (σ12.3)	8.9 (σ6.7)	16.5 (σ12.4)	3.6 (σ3.1)	16.3 (σ12.9)	13.7 (σ12.2)	20.2 (σ16.6)	11.2 (σ10.6)	19.3 (σ15.0)	16.8 (σ14.4)	23.2 (σ18.5)	14.3 (σ13.1)
Marine	Before 1950	16.4 (σ14.2)	17.8 (σ13.5)	20.9 (σ17.2)	22.3 (σ16.9)	6.0 (σ5.9)	10.5 (σ10.2)	1.8 (σ1.8)	19.2 (σ16.8)	20.7 (σ16.2)	21.5 (σ19.3)	18.7 (σ14.4)	23.7 (σ19.8)	25.1 (σ19.5)	25.8 (σ22.2)	23.1 (σ17.8)
	1950-1969	13.9 (σ11.2)	14.7 (σ11.1)	17.6 (σ13.7)	18.4 (σ13.8)	4.3 (σ4.6)	7.8 (σ8.2)	1.5 (σ1.3)	15.9 (σ13.2)	16.7 (σ12.9)	17.7 (σ15.2)	15.4 (σ11.6)	19.6 (σ15.6)	20.4 (σ15.6)	21.3 (σ17.5)	19.0 (σ14.4)
	1970-1989	9.1 (σ8.7)	8.4 (σ8.7)	11.8 (σ10.8)	11.1 (σ10.9)	4.3 (σ4.7)	8.0 (σ8.3)	1.7 (σ1.6)	11.0 (σ10.5)	10.3 (σ10.3)	12.8 (σ12.5)	9.2 (σ9.2)	13.7 (σ12.5)	12.9 (σ12.5)	15.4 (σ14.4)	11.8 (σ11.5)
Hot-Dry & Mixed-Dry	Before 1950	10.6 (σ10.3)	11.8 (σ10.2)	13.6 (σ12.7)	14.9 (σ12.9)	3.9 (σ4.2)	6.8 (σ7.4)	1.6 (σ1.9)	12.5 (σ12.4)	13.7 (σ12.4)	14.1 (σ14.3)	12.4 (σ11.2)	15.4 (σ14.7)	16.6 (σ15.0)	16.9 (σ16.6)	15.3 (σ13.8)
	1950-1969	11.6 (σ10.6)	11.8 (σ9.9)	14.6 (σ12.9)	14.8 (σ12.4)	3.8 (σ3.9)	6.8 (σ7.0)	1.8 (σ2.1)	13.4 (σ12.5)	13.6 (σ11.9)	15.3 (σ14.5)	12.4 (σ10.9)	16.2 (σ14.8)	16.4 (σ14.3)	18.0 (σ16.7)	15.1 (σ13.4)
	1970-1989	7.8 (σ8.2)	6.6 (σ7.4)	9.8 (σ10.1)	8.6 (σ9.4)	4.1 (σ3.8)	7.7 (σ7.1)	2.2 (σ2.3)	10.1 (σ9.8)	9.0 (σ9.0)	12.5 (σ12.0)	7.7 (σ8.3)	12.0 (σ11.6)	10.8 (σ10.8)	14.3 (σ13.7)	9.5 (σ10.2)
Hot-Humid	Before 1950	12.9 (σ9.5)	12.1 (σ9.1)	16.2 (σ11.7)	15.4 (σ11.4)	6.0 (σ4.5)	10.9 (σ8.0)	2.3 (σ2.5)	15.6 (σ12.2)	14.9 (σ11.7)	19.1 (σ14.6)	12.4 (σ10.6)	18.3 (σ14.4)	17.6 (σ14.0)	21.9 (σ16.6)	15.1 (σ13.0)
	1950-1969	10.6 (σ7.9)	10.4 (σ8.2)	13.3 (σ9.8)	13.1 (σ10.3)	5.0 (σ3.7)	9.2 (σ6.9)	1.8 (σ1.9)	12.2 (σ10.0)	12.0 (σ10.1)	15.5 (σ12.2)	9.7 (σ9.4)	14.3 (σ11.9)	14.1 (σ12.1)	17.5 (σ13.9)	11.7 (σ11.5)
	1970-1989	6.3 (σ5.5)	5.0 (σ5.8)	7.8 (σ7.0)	6.5 (σ7.3)	5.2 (σ3.9)	9.5 (σ7.3)	1.9 (σ2.2)	8.6 (σ7.3)	7.7 (σ7.1)	12.1 (σ9.9)	5.1 (σ6.4)	9.7 (σ8.5)	8.7 (σ8.4)	13.2 (σ11.0)	6.2 (σ7.7)

Figure A-1. Average (mean) and standard deviation (σ) of annual site energy savings (MMBtu/year) for each retrofit case in the analysis, aggregated by climate zone and vintage range.

Figure A-2 shows the average *and standard deviation (σ)* of site energy savings in percentage reduction from baseline for all upgrade scenarios, from the existing house.

		Upgrade Run / Reference Run							
		1″ insulation	2″ insulation	Storm windows	Triple pane windows	1″ insulation + storm windows	1″ insulation + triple pane windows	2″ insulation + storm windows	2″ insulation + triple pane windows
Building America Climate Zone	Vintage	Existing	Existing	Existing	Existing	Existing	Existing	Existing	Existing
Cold & Very Cold	Before 1950	18.6% (σ5.5%)	23.1% (σ6.6%)	8.3% (σ3.1%)	14.5% (σ4.9%)	21.3% (σ7.7%)	23.3% (σ9.1%)	25.7% (σ9.0%)	27.8% (σ10.1%)
	1950-1969	16.9% (σ5.4%)	21.0% (σ6.5%)	7.5% (σ2.9%)	13.4% (σ4.7%)	18.6% (σ7.4%)	20.2% (σ8.6%)	22.6% (σ8.8%)	24.3% (σ9.6%)
	1970-1989	10.0% (σ3.5%)	12.7% (σ4.1%)	8.1% (σ3.3%)	14.8% (σ5.5%)	11.4% (σ5.3%)	12.9% (σ7.8%)	14.1% (σ5.9%)	15.5% (σ8.0%)
Mixed-Humid	Before 1950	18.0% (σ4.9%)	22.3% (σ5.7%)	7.6% (σ2.7%)	13.6% (σ4.8%)	20.9% (σ7.2%)	22.9% (σ9.0%)	25.2% (σ8.3%)	27.2% (σ9.8%)
	1950-1969	16.5% (σ4.5%)	20.7% (σ5.3%)	6.8% (σ2.6%)	12.5% (σ4.6%)	18.9% (σ6.7%)	20.7% (σ8.2%)	23.1% (σ7.9%)	24.9% (σ9.1%)
	1970-1989	9.9% (σ4.5%)	12.4% (σ5.5%)	7.0% (σ2.9%)	12.9% (σ5.4%)	12.2% (σ5.9%)	14.7% (σ8.1%)	14.7% (σ7.0%)	17.0% (σ8.8%)
Marine	Before 1950	15.0% (σ7.0%)	19.6% (σ8.1%)	5.3% (σ3.3%)	9.1% (σ5.3%)	17.5% (σ8.2%)	19.0% (σ9.6%)	22.1% (σ9.3%)	23.7% (σ10.6%)
	1950-1969	14.3% (σ6.6%)	18.5% (σ7.8%)	4.0% (σ3.0%)	7.2% (σ4.9%)	16.1% (σ7.6%)	17.4% (σ8.8%)	20.4% (σ8.8%)	21.7% (σ9.9%)
	1970-1989	9.0% (σ5.7%)	11.9% (σ6.9%)	4.0% (σ3.5%)	7.7% (σ6.0%)	10.8% (σ6.8%)	12.2% (σ8.3%)	13.8% (σ7.9%)	15.2% (σ9.3%)
Hot-Dry & Mixed-Dry	Before 1950	11.9% (σ7.4%)	16.0% (σ8.9%)	4.1% (σ2.9%)	7.1% (σ4.8%)	14.0% (σ8.6%)	15.5% (σ9.8%)	17.9% (σ10.2%)	19.3% (σ11.2%)
	1950-1969	13.2% (σ7.5%)	17.0% (σ9.0%)	3.9% (σ2.8%)	7.1% (σ4.8%)	15.3% (σ8.7%)	17.0% (σ9.9%)	19.0% (σ10.3%)	20.5% (σ11.4%)
	1970-1989	7.7% (σ6.2%)	9.9% (σ7.6%)	4.4% (σ3.1%)	8.0% (σ5.4%)	10.6% (σ7.2%)	13.1% (σ8.8%)	12.6% (σ8.6%)	15.1% (σ10.0%)
Hot-Humid	Before 1950	12.8% (σ5.1%)	16.2% (σ6.2%)	5.9% (σ2.5%)	10.7% (σ4.4%)	15.7% (σ7.2%)	18.7% (σ8.5%)	18.8% (σ8.6%)	21.6% (σ9.6%)
	1950-1969	11.7% (σ4.9%)	14.8% (σ6.1%)	5.4% (σ2.4%)	9.9% (σ4.4%)	13.4% (σ7.0%)	16.4% (σ8.1%)	16.0% (σ8.5%)	18.7% (σ9.4%)
	1970-1989	6.5% (σ4.2%)	8.1% (σ5.4%)	5.9% (σ2.7%)	10.6% (σ5.0%)	9.0% (σ5.6%)	13.3% (σ7.3%)	9.9% (σ6.6%)	14.2% (σ8.1%)

Figure A-2. Average (mean) and standard deviation (σ) of percent site energy savings for upgrade scenarios compared to the existing building stock (baseline reference scenario), aggregated by climate zone and vintage range.

Figure A-3 shows the average *and standard deviation (σ)* of bill savings in $/year for each retrofit case.

		Upgrade Run / Reference Run															
		1″ insulation		2″ insulation		Storm windows	Triple pane windows		1″ insulation + storm windows		1″ insulation + triple pane windows		2″ insulation + storm windows		2″ insulation + triple pane windows		
Building America Climate Zone	Vintage	Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	
Cold & Very Cold	Before 1950	$417 (σ511)	$362 (σ452)	$515 (σ617)	$458 (σ564)	$183 (σ245)	$326 (σ429)	$43 (σ63)	$459 (σ618)	$412 (σ552)	$520 (σ724)	$352 (σ479)	$545 (σ721)	$498 (σ660)	$610 (σ821)	$438 (σ593)	
	1950-1969	$334 (σ411)	$294 (σ379)	$413 (σ499)	$371 (σ473)	$147 (σ192)	$264 (σ345)	$34 (σ51)	$351 (σ481)	$318 (σ441)	$401 (σ562)	$271 (σ394)	$420 (σ567)	$385 (σ531)	$469 (σ642)	$338 (σ488)	
	1970-1989	$197 (σ249)	$121 (σ173)	$249 (σ305)	$172 (σ234)	$166 (σ218)	$306 (σ393)	$47 (σ71)	$235 (σ329)	$167 (σ261)	$278 (σ436)	$127 (σ192)	$283 (σ379)	$215 (σ311)	$330 (σ479)	$171 (σ252)	
Mixed-Humid	Before 1950	$393 (σ403)	$350 (σ351)	$484 (σ485)	$440 (σ439)	$166 (σ178)	$295 (σ327)	$46 (σ60)	$446 (σ487)	$411 (σ433)	$505 (σ577)	$354 (σ382)	$533 (σ568)	$494 (σ519)	$590 (σ652)	$439 (σ472)	
	1950-1969	$350 (σ326)	$325 (σ305)	$434 (σ397)	$407 (σ381)	$146 (σ156)	$264 (σ288)	$41 (σ56)	$389 (σ400)	$368 (σ377)	$444 (σ480)	$322 (σ335)	$468 (σ470)	$444 (σ451)	$520 (σ545)	$398 (σ413)	
	1970-1989	$217 (σ237)	$144 (σ239)	$273 (σ294)	$199 (σ299)	$158 (σ155)	$287 (σ287)	$54 (σ72)	$271 (σ302)	$212 (σ292)	$332 (σ389)	$159 (σ256)	$322 (σ355)	$260 (σ348)	$384 (σ435)	$208 (σ316)	
Marine	Before 1950	$199 (σ288)	$228 (σ283)	$257 (σ353)	$286 (σ354)	$71 (σ116)	$124 (σ209)	$21 (σ38)	$236 (σ340)	$263 (σ336)	$260 (σ392)	$238 (σ302)	$296 (σ404)	$319 (σ405)	$320 (σ454)	$292 (σ372)	
	1950-1969	$183 (σ255)	$196 (σ243)	$234 (σ311)	$246 (σ304)	$53 (σ86)	$98 (σ153)	$18 (σ29)	$210 (σ288)	$225 (σ274)	$228 (σ324)	$204 (σ255)	$261 (σ343)	$274 (σ334)	$279 (σ376)	$252 (σ315)	
	1970-1989	$118 (σ165)	$97 (σ167)	$155 (σ205)	$134 (σ210)	$57 (σ95)	$111 (σ166)	$21 (σ34)	$144 (σ200)	$126 (σ199)	$166 (σ240)	$107 (σ177)	$181 (σ239)	$161 (σ241)	$204 (σ277)	$142 (σ220)	
Hot-Dry & Mixed-Dry	Before 1950	$148 (σ274)	$159 (σ281)	$190 (σ342)	$201 (σ354)	$56 (σ108)	$100 (σ187)	$16 (σ43)	$176 (σ329)	$186 (σ335)	$199 (σ380)	$163 (σ303)	$214 (σ396)	$225 (σ406)	$238 (σ444)	$199 (σ375)	
	1950-1969	$176 (σ297)	$171 (σ278)	$219 (σ365)	$216 (σ349)	$64 (σ102)	$120 (σ185)	$18 (σ48)	$207 (σ345)	$202 (σ326)	$238 (σ398)	$175 (σ298)	$248 (σ412)	$243 (σ396)	$277 (σ462)	$215 (σ368)	
	1970-1989	$121 (σ250)	$89 (σ221)	$151 (σ309)	$119 (σ281)	$92 (σ126)	$161 (σ227)	$24 (σ67)	$182 (σ308)	$156 (σ277)	$230 (σ379)	$104 (σ248)	$211 (σ364)	$184 (σ334)	$258 (σ431)	$131 (σ306)	
Hot-Humid	Before 1950	$245 (σ246)	$213 (σ236)	$305 (σ304)	$273 (σ297)	$115 (σ116)	$210 (σ210)	$32 (σ57)	$297 (σ318)	$266 (σ304)	$367 (σ385)	$211 (σ270)	$348 (σ375)	$315 (σ363)	$418 (σ438)	$260 (σ331)	
	1950-1969	$215 (σ181)	$186 (σ187)	$267 (σ226)	$235 (σ235)	$103 (σ91)	$189 (σ166)	$27 (σ41)	$240 (σ236)	$217 (σ233)	$307 (σ289)	$163 (σ212)	$277 (σ279)	$252 (σ278)	$343 (σ328)	$197 (σ259)	
	1970-1989	$132 (σ143)	$78 (σ148)	$161 (σ180)	$105 (σ187)	$119 (σ104)	$214 (σ192)	$32 (σ56)	$185 (σ192)	$154 (σ183)	$266 (σ261)	$75 (σ161)	$201 (σ222)	$170 (σ214)	$285 (σ286)	$90 (σ197)	

Figure A-3. Average (mean) and standard deviation (σ) of annual bill savings ($/year) for each retrofit case in the analysis, aggregated by climate zone and vintage range. Older vintages and colder climates see greater bill savings, especially with the wall-window packages in the Cold & Very Cold and Mixed-Humid climates.

Figure A-4 presents the NPV results as interquartile ranges in the format of *First Quartile, Third Quartile*, in thousands of dollars. The colors are determined from the median NPV. Darker colors in the figure indicate median NPVs further from 0, with orange for negative median values and blue for positive median values. When organized in this way, by climate zone and vintage, all median NPVs are negative for all three reference cases (as shown in Figure B-10), and for triple-pane windows on their own. Exterior storm windows on their own have positive median NPVs in the Cold & Very Cold and Mixed-Humid climate zones. The other upgrades and upgrade packages also all have negative median NPVs when looked at in relation to the existing stock, with the single exception of the exterior storms + 2” insulation + re-siding package in the pre-1950 housing stock in the Cold & Very Cold climate zone, which is positive.

For upgrades compared to non-existing-stock reference cases—the case where there was already some work planned on the home—the results tell a more complex story. Stand-alone exterior insulation + re-siding, compared to re-siding alone, has a positive median

NPV in both the 1” and 2” versions for pre-1970 vintages in every climate zone, and negative median NPV for 1970–1989 vintage housing in every climate zone. Because the infiltration reduction is modeled identically for re-siding alone versus re-siding with added exterior insulation, we know that the infiltration reduction is not driving this result. For the combined wall and window packages, the story is largely similar except that mixed-humid 1970–1989 homes have positive median NPV in the packages that use storm windows, and all vintages of homes have negative median NPV in the Hot-Dry & Mixed-Dry and Hot-Humid climate zones in the packages that use triple-pane windows.

Upgrade Run / Reference Run

Building America Climate Zone	Vintage	1” insulation		2” insulation		Storm windows	Triple pane windows		1” insulation + storm windows		1” insulation + triple pane windows		2” insulation + storm windows		2” insulation + triple pane windows	
		Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows
Cold & Very Cold	Before 1950	$-4.0, $3.4	$1.9, $9.0	$-3.5, $5.4	$2.2, $11.0	$0.3, $3.5	$-4.5, $1.5	$-1.4, $-0.4	$-3.4, $4.5	$2.0, $10.5	$-5.7, $3.2	$0.6, $7.8	$-2.9, $6.2	$2.4, $12.5	$-5.3, $5.0	$0.8, $9.7
	1950-1969	$-5.0, $1.4	$1.2, $6.9	$-4.6, $2.8	$1.3, $8.4	$0.2, $2.6	$-4.0, $0.7	$-1.3, $-0.4	$-4.4, $2.3	$1.2, $7.8	$-6.2, $1.1	$-0.3, $5.9	$-4.1, $3.3	$1.4, $9.3	$-5.9, $2.3	$-0.3, $7.2
	1970-1989	$-9.1, $-2.9	$-1.2, $1.3	$-9.2, $-2.4	$-1.5, $2.0	$0.1, $3.3	$-4.3, $1.7	$-1.3, $-0.2	$-8.4, $-0.4	$-1.2, $2.0	$-10.0, $-2.1	$-1.5, $1.0	$-8.5, $0.1	$-1.5, $2.8	$-10.1, $-1.6	$-1.8, $1.6
Mixed-Humid	Before 1950	$-4.8, $1.1	$1.9, $7.7	$-4.3, $2.6	$2.2, $9.3	$0.1, $2.6	$-5.1, $0.1	$-2.2, $-0.8	$-4.4, $2.2	$2.0, $8.8	$-7.2, $0.7	$0.5, $6.6	$-3.9, $3.4	$2.3, $10.4	$-6.8, $2.0	$0.7, $8.1
	1950-1969	$-5.7, $-0.2	$1.8, $6.8	$-5.2, $0.9	$2.0, $8.2	$0.1, $2.2	$-4.4, $0.0	$-2.0, $-0.7	$-5.3, $0.9	$1.9, $7.7	$-7.5, $-0.5	$0.5, $5.8	$-4.8, $1.8	$2.1, $9.1	$-7.1, $0.5	$0.6, $7.1
	1970-1989	$-9.9, $-4.0	$-1.1, $2.0	$-10.0, $-3.6	$-1.4, $2.7	$0.1, $2.3	$-4.7, $-0.2	$-2.1, $-0.7	$-9.1, $-1.8	$-1.0, $3.0	$-11.5, $-3.5	$-1.9, $1.3	$-9.2, $-1.1	$-1.3, $3.6	$-11.5, $-3.2	$-2.2, $1.8
Marine	Before 1950	$-8.2, $-2.7	$0.3, $4.4	$-8.1, $-2.1	$0.1, $5.2	$-1.4, $0.3	$-8.4, $-3.2	$-1.8, $-0.8	$-8.8, $-2.6	$-0.4, $4.4	$-13.1, $-4.0	$-0.6, $3.8	$-8.8, $-2.0	$-0.6, $5.1	$-13.2, $-3.5	$-0.8, $4.5
	1950-1969	$-9.4, $-3.7	$-0.2, $3.3	$-9.6, $-3.3	$-0.5, $3.9	$-1.4, $0.1	$-7.9, $-3.2	$-1.7, $-0.8	$-10.2, $-3.8	$-1.0, $3.2	$-14.1, $-5.1	$-1.2, $2.8	$-10.4, $-3.3	$-1.3, $3.8	$-14.3, $-4.7	$-1.5, $3.3
	1970-1989	$-11.5, $-5.8	$-1.8, $0.7	$-11.9, $-5.7	$-2.4, $0.8	$-1.5, $0.1	$-8.3, $-3.5	$-1.7, $-0.8	$-12.2, $-5.8	$-2.4, $0.6	$-15.9, $-6.9	$-2.6, $0.1	$-12.6, $-5.7	$-3.0, $0.8	$-16.3, $-6.9	$-3.2, $0.3
Hot-Dry & Mixed-Dry	Before 1950	$-9.4, $-4.3	$-0.7, $2.9	$-9.7, $-4.0	$-1.2, $3.4	$-1.4, $0.1	$-8.2, $-3.4	$-2.0, $-0.9	$-10.2, $-4.1	$-1.6, $2.7	$-14.5, $-6.0	$-1.9, $1.8	$-10.4, $-3.7	$-2.0, $3.2	$-14.8, $-5.7	$-2.3, $2.3
	1950-1969	$-9.9, $-4.5	$-0.8, $2.9	$-10.2, $-4.1	$-1.2, $3.4	$-1.2, $0.3	$-7.2, $-3.0	$-2.0, $-0.9	$-10.4, $-3.9	$-1.5, $3.0	$-14.5, $-6.0	$-1.9, $2.0	$-10.7, $-3.5	$-2.0, $3.5	$-14.8, $-5.7	$-2.4, $2.4
	1970-1989	$-12.9, $-6.5	$-2.0, $0.5	$-13.5, $-6.6	$-2.7, $0.5	$-1.0, $0.8	$-7.1, $-2.7	$-2.2, $-0.9	$-13.0, $-5.7	$-2.4, $0.9	$-17.4, $-8.0	$-3.4, $-0.4	$-13.6, $-5.7	$-3.2, $0.9	$-18.0, $-8.0	$-4.1, $-0.5
Hot-Humid	Before 1950	$-7.3, $-2.6	$0.3, $3.8	$-7.3, $-2.0	$0.1, $4.6	$-0.4, $1.1	$-6.1, $-1.9	$-3.4, $-1.6	$-6.9, $-0.6	$0.0, $4.5	$-11.2, $-3.6	$-2.4, $1.9	$-6.9, $-0.3	$-0.1, $5.3	$-11.3, $-3.1	$-2.5, $2.6
	1950-1969	$-9.1, $-4.0	$-0.3, $2.9	$-9.3, $-3.6	$-0.6, $3.4	$-0.5, $0.9	$-5.9, $-2.0	$-3.2, $-1.6	$-8.4, $-0.7	$-0.6, $3.4	$-12.6, $-4.2	$-2.9, $0.9	$-8.4, $-0.4	$-0.9, $3.9	$-12.6, $-3.9	$-3.1, $1.2
	1970-1989	$-13.2, $-7.2	$-2.0, $0.1	$-13.8, $-7.3	$-2.8, $0.0	$-0.4, $1.1	$-6.1, $-2.0	$-3.4, $-1.6	$-11.4, $-0.4	$-2.2, $0.7	$-15.5, $-5.1	$-4.2, $-1.3	$-11.9, $-0.4	$-2.9, $0.7	$-16.0, $-5.0	$-4.7, $-1.4

Figure A-4. First and third quartile of NPV (thousand $) for each retrofit case in the analysis, aggregated by climate zone and vintage range. Cells are colored based on the median NPV.

Figure A-5 shows the nationwide long-run marginal carbon emissions reduction for all four emissions factor scenarios included in the analysis in order to represent the uncertainty in the future of the electric grid and in the appropriate lifetime for the measures, as described in Section 2.8. Regardless of the emissions factors used, the conclusions remain the same as those discussed in Figure 6—the greatest emissions reductions come from the packages, followed closely by the stand-alone insulation measures.

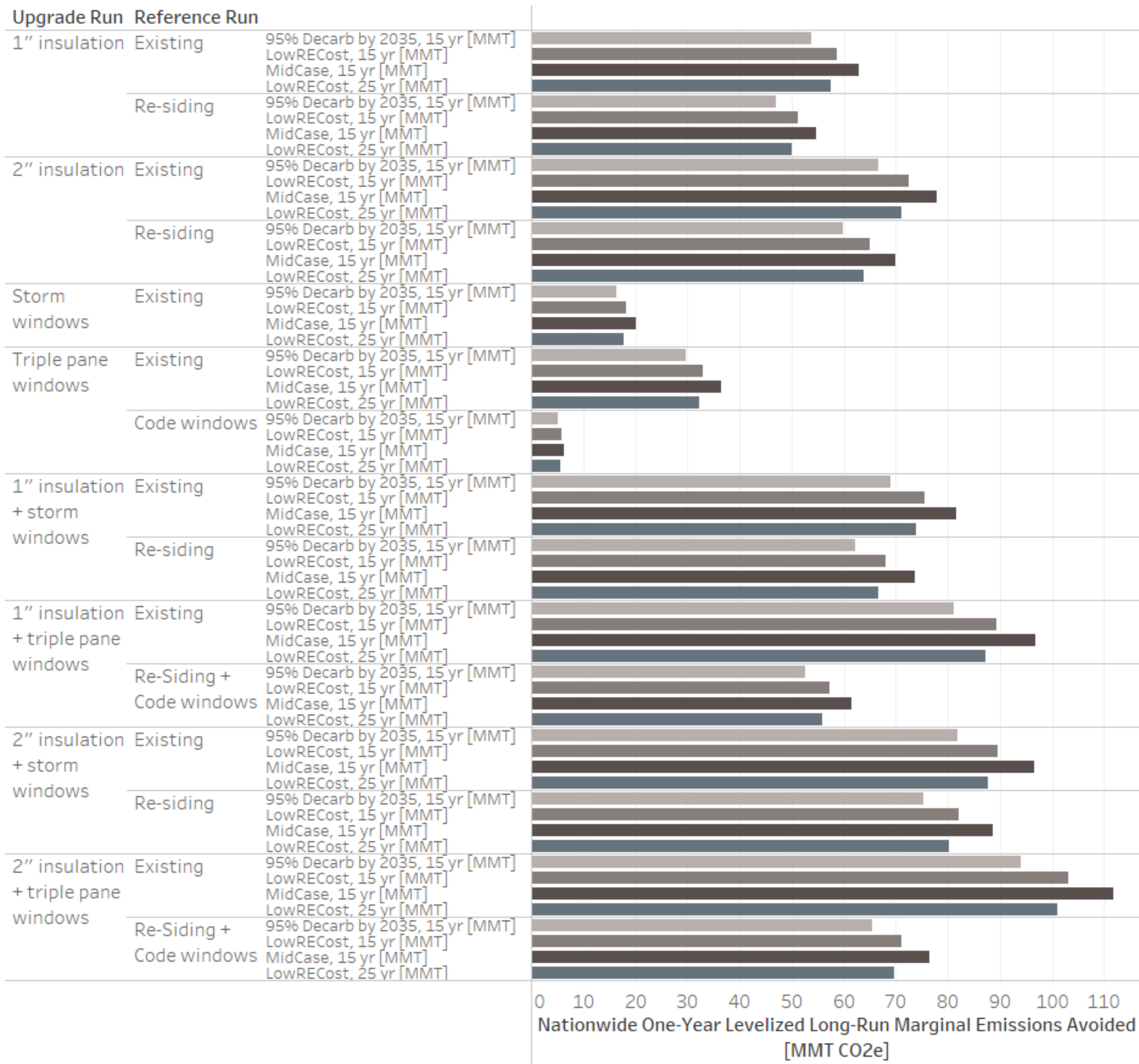

Figure A-5. Total one-year nationwide carbon emissions reduction if every house represented in the analysis were to have the specified retrofit case implemented. The results are shown using four different sets of emissions factors to reflect the uncertainty in the future of the electric grid—even within this uncertainty, clear trends emerge including the relatively small increase in emissions reduction for 2" vs. 1" exterior insulation.

Figure A-6 presents the emissions results in terms of average one-year per-house avoided carbon emissions for each of the retrofit cases in this analysis, aggregated by climate zone and vintage. Emissions results are shown for all four of the sets of emissions factors included in the analysis, as described in Section 2.8.

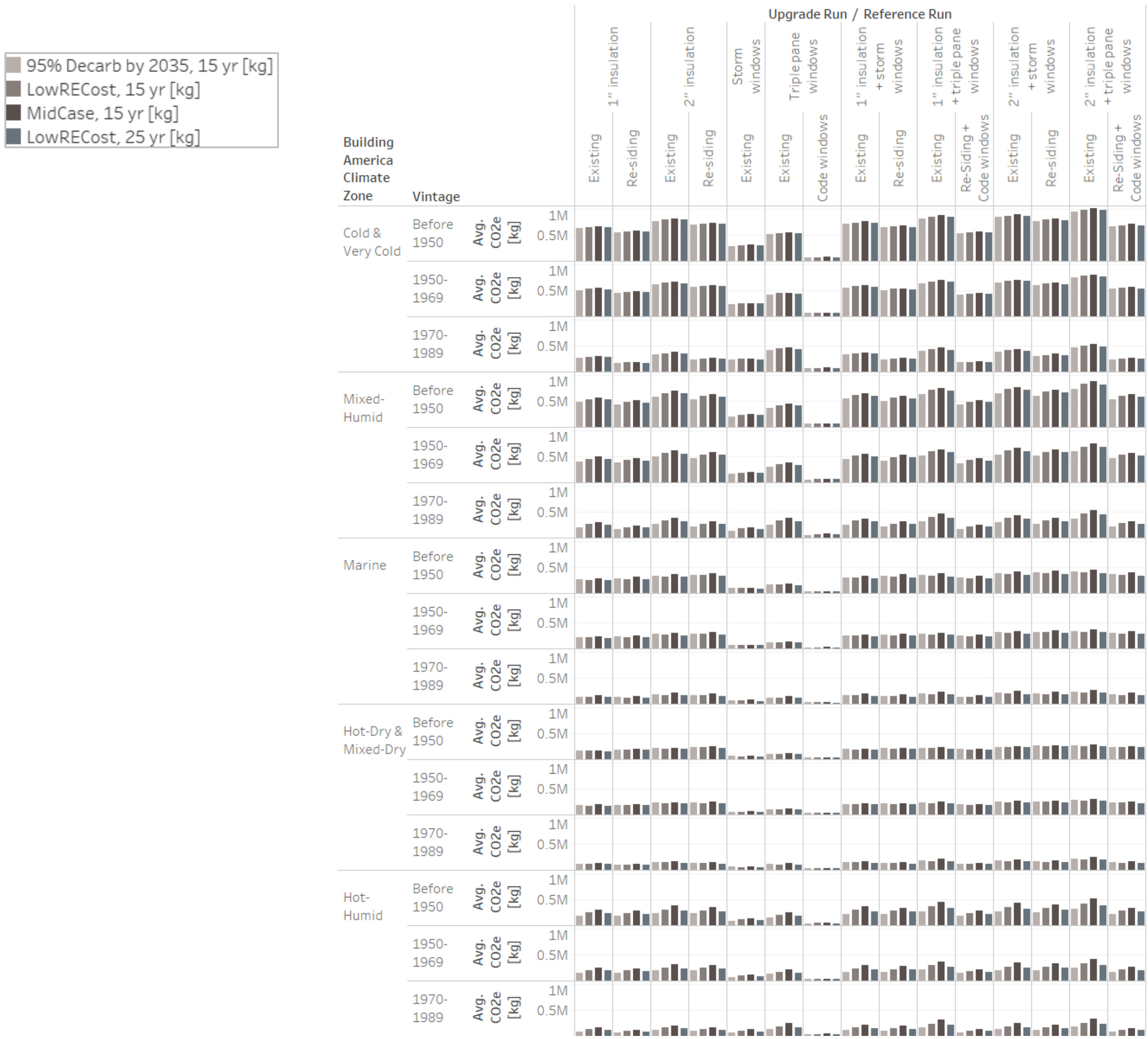

Figure A-6. Average per-house avoided carbon emissions (kg CO_{2e}/yr) for one year aggregated by climate zone and vintage range, for each retrofit case in the analysis, for each set of emissions factors included in the analysis.

Figure A-6 shows considerable variation in avoided carbon emissions results between the four sets of emissions factors. However, most of the overall trends and takeaways are constant regardless of which set of emissions factors you focus on.

Figure A-7 through Figure A-12 show select results with the climate zones ungrouped. As shown in Figure A-7, some of the ungrouped climate zones have lower sample sizes, below 1,000 models, and therefore have larger uncertainty in their aggregate results. None of the climate zone, vintage, and retrofit combinations fall below 150 samples though. At the sample sizes shown in this series of figures, there is useful information in the results, just information with less certainty and rigor than when using our current standard threshold of 1,000 samples.

Building America Ungrouped Climate Zones	Vintage	Existing Applicable	Re-Siding Applicable	Code Compliant Windows Applicable	Re-siding & code-minimum windows Applicable	1″ insulation + re-siding Applicable	2″ insulation + re-siding Applicable	Exterior low-E storm windows Applicable	Triple pane windows Applicable	Exterior storms + 1″ insulation + re-siding Applicable	Triple pane + 1″ insulation + re-siding Applicable	Exterior storms + 2″ insulation + re-siding Applicable	Triple pane + 2″ insulation + re-siding Applicable
Cold	Before 1950	27,342	22,222	13,226	24,644	22,222	22,222	13,226	13,226	24,644	24,644	24,644	24,644
	1950-1969	27,340	20,530	12,098	23,503	20,530	20,530	12,098	12,098	23,503	23,503	23,503	23,503
	1970-1989	21,714	15,808	7,809	17,844	15,808	15,808	7,809	7,809	17,844	17,844	17,844	17,844
Hot-Dry	Before 1950	3,930	3,779	2,481	3,880	3,779	3,779	2,481	2,481	3,880	3,880	3,880	3,880
	1950-1969	8,539	8,100	5,633	8,414	8,100	8,100	5,633	5,633	8,414	8,414	8,414	8,414
	1970-1989	8,620	7,959	6,139	8,440	7,959	7,959	6,139	6,139	8,440	8,440	8,440	8,440
Hot-Humid	Before 1950	3,953	3,253	2,991	3,797	3,254	3,254	2,991	2,991	3,797	3,797	3,797	3,797
	1950-1969	10,643	7,738	8,294	9,995	7,738	7,738	8,294	8,294	9,995	9,995	9,995	9,995
	1970-1989	15,334	9,789	11,898	14,050	9,789	9,789	11,898	11,898	14,050	14,050	14,050	14,050
Marine	Before 1950	2,936	2,888	1,632	2,914	2,888	2,888	1,632	1,632	2,914	2,914	2,914	2,914
	1950-1969	3,934	3,863	2,200	3,894	3,863	3,863	2,200	2,200	3,894	3,894	3,894	3,894
	1970-1989	3,770	3,664	1,970	3,717	3,664	3,664	1,970	1,970	3,717	3,717	3,717	3,717
Mixed-Dry	Before 1950	284	247	181	270	247	247	181	181	270	270	270	270
	1950-1969	591	472	370	550	472	472	370	370	550	550	550	550
	1970-1989	620	524	436	594	524	524	436	436	594	594	594	594
Mixed-Humid	Before 1950	14,410	12,453	7,639	13,482	12,453	12,453	7,639	7,639	13,482	13,482	13,482	13,482
	1950-1969	21,506	18,158	10,980	19,939	18,158	18,158	10,980	10,980	19,939	19,939	19,939	19,939
	1970-1989	22,034	17,976	10,936	20,100	17,976	17,976	10,936	10,936	20,100	20,100	20,100	20,100
Very Cold	Before 1950	593	494	322	550	494	494	322	322	550	550	550	550
	1950-1969	474	406	229	436	406	406	229	229	436	436	436	436
	1970-1989	555	390	199	438	390	390	199	199	438	438	438	438
Grand Total		**199,122**	**160,713**	**107,663**	**181,451**	**160,714**	**160,714**	**107,663**	**107,663**	**181,451**	**181,451**	**181,451**	**181,451**

Figure A-7. Number of ResStock sample houses eligible for each of the retrofit components, aggregated by ungrouped climate zone and vintage range. This is an expanded version of Figure 4.

		Upgrade Run / Reference Run														
		1″ insulation		2″ insulation		Storm windows	Triple pane windows		1″ insulation + storm windows		1″ insulation + triple pane windows		2″ insulation + storm windows		2″ insulation + triple pane windows	
Building America Ungrouped Climate Zones	Vintage	Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows
Very Cold	Before 1950	38.1 (σ28.5)	28.0 (σ27.1)	46.5 (σ34.2)	36.3 (σ33.2)	24.6 (σ15.3)	44.0 (σ27.2)	6.8 (σ4.8)	47.6 (σ35.3)	38.5 (σ32.5)	58.0 (σ43.3)	29.4 (σ28.5)	55.2 (σ40.7)	46.0 (σ38.3)	65.6 (σ48.1)	37.0 (σ34.8)
	1950-1969	25.2 (σ17.5)	14.9 (σ14.5)	30.6 (σ20.6)	20.3 (σ18.0)	20.4 (σ12.7)	37.4 (σ23.7)	5.7 (σ3.9)	33.3 (σ23.5)	23.8 (σ19.6)	41.3 (σ31.4)	17.0 (σ15.5)	38.3 (σ26.3)	28.8 (σ22.7)	46.4 (σ33.7)	22.1 (σ19.1)
	1970-1989	20.4 (σ12.9)	10.8 (σ7.2)	25.3 (σ15.2)	15.7 (σ10.3)	18.5 (σ11.7)	34.0 (σ20.9)	6.1 (σ4.5)	26.0 (σ17.6)	17.5 (σ13.1)	32.5 (σ24.4)	12.5 (σ8.4)	30.4 (σ19.6)	21.9 (σ15.0)	36.9 (σ25.7)	16.8 (σ11.4)
Cold	Before 1950	37.0 (σ22.6)	32.3 (σ20.4)	45.3 (σ27.0)	40.7 (σ25.2)	16.9 (σ11.5)	29.9 (σ20.0)	4.2 (σ3.1)	41.8 (σ28.1)	37.6 (σ25.2)	48.2 (σ33.2)	31.7 (σ22.4)	49.4 (σ32.6)	45.2 (σ30.1)	55.8 (σ37.3)	39.3 (σ27.6)
	1950-1969	29.9 (σ18.2)	26.6 (σ17.3)	36.9 (σ21.9)	33.5 (σ21.3)	14.0 (σ9.3)	25.0 (σ16.4)	3.5 (σ2.6)	32.9 (σ22.3)	30.0 (σ20.6)	38.1 (σ26.3)	25.2 (σ18.8)	38.9 (σ26.1)	36.0 (σ24.7)	44.2 (σ29.6)	31.3 (σ23.3)
	1970-1989	15.8 (σ10.5)	10.1 (σ7.5)	19.9 (σ12.6)	14.3 (σ9.9)	13.4 (σ9.4)	24.6 (σ16.7)	4.1 (σ3.1)	19.5 (σ14.3)	14.4 (σ11.5)	24.1 (σ19.4)	10.8 (σ8.4)	23.2 (σ16.2)	18.1 (σ13.4)	27.8 (σ20.8)	14.5 (σ11.0)
Mixed-Humid	Before 1950	29.1 (σ19.6)	26.0 (σ16.1)	35.7 (σ23.2)	32.6 (σ20.1)	12.5 (σ9.2)	22.8 (σ17.0)	3.8 (σ3.0)	33.4 (σ24.3)	30.6 (σ20.8)	38.8 (σ29.2)	26.4 (σ18.1)	39.5 (σ28.0)	36.7 (σ24.7)	44.9 (σ32.6)	32.5 (σ22.3)
	1950-1969	24.4 (σ15.7)	23.0 (σ13.8)	30.2 (σ18.8)	28.8 (σ17.2)	10.1 (σ7.4)	18.7 (σ13.7)	3.3 (σ2.6)	27.4 (σ19.3)	26.1 (σ17.4)	31.7 (σ23.1)	23.0 (σ15.5)	32.6 (σ22.5)	31.4 (σ20.8)	37.0 (σ26.0)	28.2 (σ19.2)
	1970-1989	13.2 (σ10.1)	10.3 (σ9.9)	16.6 (σ12.3)	13.7 (σ12.3)	8.9 (σ6.7)	16.5 (σ12.4)	3.6 (σ3.1)	16.3 (σ12.9)	13.7 (σ12.2)	20.2 (σ16.6)	11.2 (σ10.6)	19.3 (σ15.0)	16.8 (σ14.4)	23.2 (σ18.5)	14.3 (σ13.1)
Marine	Before 1950	16.4 (σ14.2)	17.8 (σ13.5)	20.9 (σ17.2)	22.3 (σ16.9)	6.0 (σ5.9)	10.5 (σ10.2)	1.8 (σ1.8)	19.2 (σ16.8)	20.7 (σ16.2)	21.5 (σ19.3)	18.7 (σ14.4)	23.7 (σ19.8)	25.1 (σ19.5)	25.8 (σ22.2)	23.1 (σ17.8)
	1950-1969	13.9 (σ11.2)	14.7 (σ11.1)	17.6 (σ13.7)	18.4 (σ13.8)	4.3 (σ4.6)	7.8 (σ8.2)	1.5 (σ1.3)	15.9 (σ13.2)	16.7 (σ12.9)	17.7 (σ15.2)	15.4 (σ11.6)	19.6 (σ15.6)	20.4 (σ15.6)	21.3 (σ17.5)	19.0 (σ14.4)
	1970-1989	9.1 (σ8.7)	8.4 (σ8.7)	11.8 (σ10.8)	11.1 (σ10.9)	4.3 (σ4.7)	8.0 (σ8.3)	1.7 (σ1.6)	11.0 (σ10.5)	10.3 (σ10.3)	12.8 (σ12.5)	9.2 (σ9.2)	13.7 (σ12.5)	12.9 (σ12.5)	15.4 (σ14.4)	11.8 (σ11.5)
Mixed-Dry	Before 1950	23.5 (σ16.3)	23.6 (σ15.5)	29.6 (σ19.8)	29.7 (σ19.4)	8.8 (σ6.8)	16.9 (σ12.7)	3.6 (σ2.9)	27.1 (σ20.2)	27.2 (σ19.3)	32.1 (σ24.3)	24.3 (σ17.6)	32.6 (σ23.7)	32.8 (σ23.2)	37.7 (σ27.6)	29.8 (σ21.6)
	1950-1969	24.9 (σ15.5)	23.7 (σ13.1)	30.9 (σ18.5)	29.7 (σ16.3)	7.7 (σ5.2)	15.4 (σ9.9)	3.4 (σ2.2)	26.2 (σ18.4)	25.2 (σ16.2)	31.2 (σ21.0)	22.8 (σ15.4)	31.4 (σ21.7)	30.4 (σ19.8)	36.4 (σ24.1)	27.9 (σ19.1)
	1970-1989	16.4 (σ14.3)	13.7 (σ12.9)	20.7 (σ17.2)	18.0 (σ15.9)	7.2 (σ5.9)	15.1 (σ10.8)	3.8 (σ2.5)	19.4 (σ16.4)	16.9 (σ14.6)	24.8 (σ19.2)	14.8 (σ13.4)	23.2 (σ19.3)	20.7 (σ17.6)	28.6 (σ21.8)	18.6 (σ16.5)
Hot-Dry	Before 1950	9.7 (σ9.2)	11.0 (σ9.3)	12.6 (σ11.3)	13.9 (σ11.7)	3.5 (σ3.7)	6.0 (σ6.2)	1.5 (σ1.7)	11.5 (σ10.9)	12.8 (σ11.2)	12.9 (σ12.4)	11.6 (σ10.1)	14.2 (σ13.1)	15.5 (σ13.5)	15.5 (σ14.5)	14.2 (σ12.5)
	1950-1969	10.9 (σ9.7)	11.1 (σ9.2)	13.7 (σ11.9)	13.9 (σ11.5)	3.5 (σ3.6)	6.3 (σ6.4)	1.7 (σ2.1)	12.6 (σ11.5)	12.8 (σ11.1)	14.2 (σ13.3)	11.7 (σ10.1)	15.2 (σ13.7)	15.5 (σ13.4)	16.8 (σ15.4)	14.3 (σ12.5)
	1970-1989	7.2 (σ7.2)	6.1 (σ6.7)	9.1 (σ8.9)	8.0 (σ8.4)	3.9 (σ3.6)	7.1 (σ6.5)	2.0 (σ2.3)	9.5 (σ8.9)	8.4 (σ8.2)	11.6 (σ10.8)	7.2 (σ7.5)	11.2 (σ10.5)	10.1 (σ9.8)	13.3 (σ12.3)	8.9 (σ9.2)
Hot-Humid	Before 1950	12.9 (σ9.5)	12.1 (σ9.1)	16.2 (σ11.7)	15.4 (σ11.4)	6.0 (σ4.5)	10.9 (σ8.0)	2.3 (σ2.5)	15.6 (σ12.2)	14.9 (σ11.7)	19.1 (σ14.6)	12.4 (σ10.6)	18.3 (σ14.4)	17.6 (σ14.0)	21.9 (σ16.6)	15.1 (σ13.0)
	1950-1969	10.6 (σ7.9)	10.4 (σ8.2)	13.3 (σ9.8)	13.1 (σ10.3)	5.0 (σ3.7)	9.2 (σ6.9)	1.8 (σ1.9)	12.2 (σ10.0)	12.0 (σ10.1)	15.5 (σ12.2)	9.7 (σ9.4)	14.3 (σ11.9)	14.1 (σ12.1)	17.5 (σ13.9)	11.7 (σ11.5)
	1970-1989	6.3 (σ5.5)	5.0 (σ5.8)	7.8 (σ7.0)	6.5 (σ7.3)	5.2 (σ3.9)	9.5 (σ7.3)	1.9 (σ2.2)	8.6 (σ7.3)	7.7 (σ7.1)	12.1 (σ9.9)	5.1 (σ6.4)	9.7 (σ8.5)	8.7 (σ8.4)	13.2 (σ11.0)	6.2 (σ7.7)

Figure A-8. Average (mean) and standard deviation (σ) of annual site energy savings (MMBtu/year) for each retrofit case, aggregated by ungrouped climate zone and vintage range. This is an expanded version of Figure A-1.

Building America Ungrouped Climate Zones	Vintage	Upgrade Run / Reference Run							
		1″ insulation	2″ insulation	Storm windows	Triple pane windows	1″ insulation + storm windows	1″ insulation + triple pane windows	2″ insulation + storm windows	2″ insulation + triple pane windows
		Existing	Existing	Existing	Existing	Existing	Existing	Existing	Existing
Very Cold	Before 1950	13.5% (σ6.1%)	16.6% (σ7.3%)	9.8% (σ3.3%)	17.1% (σ5.3%)	18.6% (σ7.8%)	22.4% (σ9.8%)	21.8% (σ9.0%)	25.7% (σ10.7%)
	1950-1969	11.1% (σ4.3%)	13.4% (σ5.2%)	9.0% (σ3.1%)	16.8% (σ5.2%)	14.6% (σ6.1%)	17.9% (σ8.8%)	16.9% (σ6.8%)	20.0% (σ9.2%)
	1970-1989	10.0% (σ2.9%)	12.6% (σ3.3%)	9.1% (σ3.4%)	16.3% (σ5.1%)	11.9% (σ5.0%)	13.6% (σ7.7%)	14.5% (σ5.3%)	16.1% (σ7.6%)
Cold	Before 1950	18.6% (σ5.5%)	23.2% (σ6.5%)	8.2% (σ3.1%)	14.4% (σ4.9%)	21.3% (σ7.6%)	23.3% (σ9.1%)	25.8% (σ9.0%)	27.9% (σ10.1%)
	1950-1969	17.0% (σ5.4%)	21.1% (σ6.5%)	7.5% (σ2.9%)	13.4% (σ4.7%)	18.7% (σ7.4%)	20.3% (σ8.6%)	22.7% (σ8.8%)	24.4% (σ9.6%)
	1970-1989	10.0% (σ3.5%)	12.7% (σ4.1%)	8.0% (σ3.3%)	14.8% (σ5.5%)	11.4% (σ5.3%)	12.9% (σ7.8%)	14.1% (σ5.9%)	15.5% (σ8.1%)
Mixed-Humid	Before 1950	18.0% (σ4.9%)	22.3% (σ5.7%)	7.6% (σ2.7%)	13.6% (σ4.8%)	20.9% (σ7.2%)	22.9% (σ9.0%)	25.2% (σ8.3%)	27.2% (σ9.8%)
	1950-1969	16.5% (σ4.5%)	20.7% (σ5.3%)	6.8% (σ2.6%)	12.5% (σ4.6%)	18.9% (σ6.7%)	20.7% (σ8.2%)	23.1% (σ7.9%)	24.9% (σ9.1%)
	1970-1989	9.9% (σ4.5%)	12.4% (σ5.5%)	7.0% (σ2.9%)	12.9% (σ5.4%)	12.2% (σ5.9%)	14.7% (σ8.1%)	14.7% (σ7.0%)	17.0% (σ8.8%)
Marine	Before 1950	15.0% (σ7.0%)	19.6% (σ8.1%)	5.3% (σ3.3%)	9.1% (σ5.3%)	17.5% (σ8.2%)	19.0% (σ9.6%)	22.1% (σ9.3%)	23.7% (σ10.6%)
	1950-1969	14.3% (σ6.6%)	18.5% (σ7.8%)	4.0% (σ3.0%)	7.2% (σ4.9%)	16.1% (σ7.6%)	17.4% (σ8.8%)	20.4% (σ8.8%)	21.7% (σ9.9%)
	1970-1989	9.0% (σ5.7%)	11.9% (σ6.9%)	4.0% (σ3.5%)	7.7% (σ6.0%)	10.8% (σ6.8%)	12.2% (σ8.3%)	13.8% (σ7.9%)	15.2% (σ9.3%)
Mixed-Dry	Before 1950	17.5% (σ6.4%)	22.4% (σ7.3%)	6.3% (σ2.8%)	11.6% (σ4.9%)	20.9% (σ8.3%)	23.8% (σ10.0%)	25.9% (σ9.7%)	28.6% (σ11.1%)
	1950-1969	19.0% (σ6.4%)	24.3% (σ7.3%)	5.5% (σ2.9%)	11.1% (σ4.8%)	21.2% (σ8.7%)	24.3% (σ9.6%)	26.0% (σ10.5%)	28.6% (σ11.0%)
	1970-1989	11.1% (σ6.9%)	14.2% (σ8.2%)	5.4% (σ3.2%)	11.7% (σ5.6%)	14.2% (σ7.9%)	18.6% (σ9.5%)	17.4% (σ9.4%)	21.7% (σ10.6%)
Hot-Dry	Before 1950	11.6% (σ7.3%)	15.5% (σ8.8%)	3.8% (σ2.9%)	6.7% (σ4.6%)	13.6% (σ8.5%)	15.0% (σ9.6%)	17.4% (σ10.1%)	18.7% (σ11.0%)
	1950-1969	12.8% (σ7.4%)	16.6% (σ8.9%)	3.8% (σ2.8%)	6.8% (σ4.7%)	15.0% (σ8.6%)	16.5% (σ9.8%)	18.6% (σ10.2%)	19.9% (σ11.2%)
	1970-1989	7.5% (σ6.0%)	9.5% (σ7.4%)	4.3% (σ3.1%)	7.7% (σ5.3%)	10.4% (σ7.1%)	12.7% (σ8.7%)	12.3% (σ8.4%)	14.7% (σ9.8%)
Hot-Humid	Before 1950	12.8% (σ5.1%)	16.2% (σ6.2%)	5.9% (σ2.5%)	10.7% (σ4.4%)	15.7% (σ7.2%)	18.7% (σ8.5%)	18.8% (σ8.6%)	21.6% (σ9.6%)
	1950-1969	11.7% (σ4.9%)	14.8% (σ6.1%)	5.4% (σ2.4%)	9.9% (σ4.4%)	13.4% (σ7.0%)	16.4% (σ8.1%)	16.0% (σ8.5%)	18.7% (σ9.4%)
	1970-1989	6.5% (σ4.2%)	8.1% (σ5.4%)	5.9% (σ2.7%)	10.6% (σ5.0%)	9.0% (σ5.6%)	13.3% (σ7.3%)	9.9% (σ6.6%)	14.2% (σ8.1%)

Figure A-9. Average (mean) and standard deviation (σ) of percent site energy savings for upgrade scenarios compared to the existing building stock (baseline reference scenario), aggregated by ungrouped climate zone and vintage range. This is an expanded version of Figure A-2.

Upgrade Run / Reference Run

Building America Ungrouped Climate Zones	Vintage	1″ insulation		2″ insulation		Storm windows	Triple pane windows		1″ insulation + storm windows		1″ insulation + triple pane windows		2″ insulation + storm windows		2″ insulation + triple pane windows	
		Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows
Very Cold	Before 1950	$393 (σ610)	$264 (σ516)	$497 (σ730)	$361 (σ640)	$283 (σ340)	$510 (σ611)	$82 (σ95)	$508 (σ766)	$393 (σ655)	$625 (σ936)	$266 (σ544)	$605 (σ881)	$470 (σ773)	$718 (σ1,042)	$347 (σ670)
	1950-1969	$287 (σ354)	$141 (σ272)	$356 (σ422)	$203 (σ346)	$215 (σ283)	$385 (σ528)	$64 (σ83)	$371 (σ482)	$242 (σ400)	$440 (σ642)	$169 (σ300)	$436 (σ546)	$288 (σ465)	$504 (σ697)	$223 (σ374)
	1970-1989	$330 (σ320)	$166 (σ166)	$417 (σ384)	$243 (σ240)	$263 (σ272)	$487 (σ449)	$83 (σ96)	$393 (σ414)	$248 (σ297)	$467 (σ536)	$186 (σ194)	$462 (σ470)	$335 (σ347)	$539 (σ581)	$246 (σ265)
Cold	Before 1950	$417 (σ509)	$365 (σ451)	$515 (σ614)	$460 (σ562)	$182 (σ241)	$323 (σ421)	$42 (σ62)	$458 (σ614)	$412 (σ550)	$518 (σ718)	$353 (σ478)	$544 (σ716)	$498 (σ658)	$607 (σ815)	$439 (σ591)
	1950-1969	$335 (σ412)	$297 (σ380)	$414 (σ501)	$375 (σ474)	$146 (σ189)	$262 (σ339)	$34 (σ50)	$350 (σ481)	$320 (σ442)	$400 (σ561)	$273 (σ396)	$420 (σ567)	$387 (σ532)	$468 (σ641)	$340 (σ490)
	1970-1989	$194 (σ246)	$120 (σ173)	$246 (σ302)	$171 (σ233)	$165 (σ215)	$302 (σ390)	$46 (σ70)	$232 (σ325)	$165 (σ260)	$275 (σ433)	$126 (σ192)	$280 (σ375)	$214 (σ310)	$327 (σ475)	$170 (σ252)
Mixed-Humid	Before 1950	$393 (σ403)	$350 (σ351)	$484 (σ485)	$440 (σ439)	$166 (σ178)	$295 (σ327)	$46 (σ60)	$446 (σ487)	$411 (σ433)	$505 (σ577)	$354 (σ382)	$533 (σ568)	$494 (σ519)	$590 (σ652)	$439 (σ472)
	1950-1969	$350 (σ326)	$325 (σ305)	$434 (σ397)	$407 (σ381)	$146 (σ156)	$264 (σ288)	$41 (σ56)	$389 (σ400)	$368 (σ377)	$444 (σ480)	$322 (σ335)	$468 (σ470)	$444 (σ451)	$520 (σ545)	$398 (σ413)
	1970-1989	$217 (σ237)	$144 (σ239)	$273 (σ294)	$199 (σ299)	$158 (σ155)	$287 (σ287)	$54 (σ72)	$271 (σ302)	$212 (σ292)	$332 (σ389)	$159 (σ256)	$322 (σ355)	$260 (σ348)	$384 (σ435)	$208 (σ316)
Marine	Before 1950	$199 (σ288)	$228 (σ283)	$257 (σ353)	$286 (σ354)	$71 (σ116)	$124 (σ209)	$21 (σ38)	$236 (σ340)	$263 (σ336)	$260 (σ392)	$238 (σ302)	$296 (σ404)	$319 (σ405)	$320 (σ454)	$292 (σ372)
	1950-1969	$183 (σ255)	$196 (σ243)	$234 (σ311)	$246 (σ304)	$53 (σ86)	$98 (σ153)	$18 (σ29)	$210 (σ288)	$225 (σ274)	$228 (σ324)	$204 (σ255)	$261 (σ343)	$274 (σ334)	$279 (σ376)	$252 (σ315)
	1970-1989	$118 (σ165)	$97 (σ167)	$155 (σ205)	$134 (σ210)	$57 (σ95)	$111 (σ166)	$21 (σ34)	$144 (σ200)	$126 (σ199)	$166 (σ240)	$107 (σ177)	$181 (σ239)	$161 (σ241)	$204 (σ277)	$142 (σ220)
Mixed-Dry	Before 1950	$257 (σ477)	$266 (σ446)	$324 (σ584)	$336 (σ560)	$94 (σ161)	$186 (σ292)	$35 (σ67)	$291 (σ559)	$294 (σ525)	$345 (σ649)	$264 (σ483)	$357 (σ663)	$361 (σ636)	$414 (σ750)	$325 (σ595)
	1950-1969	$274 (σ557)	$254 (σ462)	$342 (σ668)	$322 (σ577)	$95 (σ134)	$182 (σ247)	$34 (σ52)	$284 (σ593)	$269 (σ510)	$334 (σ656)	$245 (σ478)	$342 (σ702)	$329 (σ621)	$391 (σ761)	$299 (σ591)
	1970-1989	$184 (σ478)	$152 (σ401)	$239 (σ580)	$209 (σ505)	$100 (σ187)	$201 (σ329)	$44 (σ82)	$233 (σ543)	$210 (σ468)	$312 (σ626)	$161 (σ421)	$283 (σ642)	$254 (σ569)	$352 (σ722)	$209 (σ524)
Hot-Dry	Before 1950	$142 (σ251)	$153 (σ263)	$183 (σ314)	$193 (σ332)	$53 (σ101)	$95 (σ173)	$15 (σ40)	$167 (σ302)	$180 (σ313)	$189 (σ348)	$157 (σ283)	$206 (σ364)	$218 (σ380)	$226 (σ407)	$193 (σ350)
	1950-1969	$171 (σ270)	$166 (σ259)	$213 (σ334)	$208 (σ327)	$62 (σ99)	$116 (σ179)	$17 (σ48)	$202 (σ320)	$198 (σ308)	$231 (σ372)	$171 (σ280)	$242 (σ382)	$238 (σ373)	$268 (σ430)	$209 (σ345)
	1970-1989	$118 (σ223)	$87 (σ201)	$146 (σ277)	$115 (σ255)	$91 (σ120)	$158 (σ217)	$23 (σ65)	$178 (σ281)	$152 (σ256)	$224 (σ352)	$101 (σ228)	$207 (σ332)	$180 (σ307)	$252 (σ399)	$127 (σ281)
Hot-Humid	Before 1950	$245 (σ246)	$213 (σ236)	$305 (σ304)	$273 (σ297)	$115 (σ116)	$210 (σ210)	$32 (σ57)	$297 (σ318)	$266 (σ304)	$367 (σ385)	$211 (σ270)	$348 (σ375)	$315 (σ363)	$418 (σ438)	$260 (σ331)
	1950-1969	$215 (σ181)	$186 (σ187)	$267 (σ226)	$235 (σ235)	$103 (σ91)	$189 (σ166)	$27 (σ41)	$240 (σ236)	$217 (σ233)	$307 (σ289)	$163 (σ212)	$277 (σ279)	$252 (σ278)	$343 (σ328)	$197 (σ259)
	1970-1989	$132 (σ143)	$78 (σ148)	$161 (σ180)	$105 (σ187)	$119 (σ104)	$214 (σ192)	$32 (σ56)	$185 (σ192)	$154 (σ183)	$266 (σ261)	$75 (σ161)	$201 (σ222)	$170 (σ214)	$285 (σ286)	$90 (σ197)

Figure A-10. Average (mean) and standard deviation (σ) of annual bill savings ($/year) for each retrofit case in the analysis, aggregated by ungrouped climate zone and vintage range. This is an expanded version of Figure A-3.

Building America Ungrouped Climate Zones	Vintage	Upgrade Run / Reference Run: 1″ insulation		2″ insulation		Storm windows	Triple pane windows		1″ insulation + storm windows		1″ insulation + triple pane windows		2″ insulation + storm windows		2″ insulation + triple pane windows	
		Existing	Re-siding	Existing	Re-siding	Existing	Existing	Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows	Existing	Re-siding	Existing	Re-Siding + Code windows
Very Cold	Before 1950	54%	74%	59%	76%	54%	42%	26%	70%	78%	64%	74%	73%	79%	66%	76%
	1950-1969	45%	68%	49%	72%	47%	38%	20%	61%	76%	55%	64%	63%	77%	58%	69%
	1970-1989	35%	55%	40%	59%	34%	29%	21%	49%	61%	47%	57%	52%	63%	50%	61%
Cold	Before 1950	56%	77%	62%	78%	45%	28%	14%	68%	79%	58%	78%	73%	79%	63%	79%
	1950-1969	43%	69%	49%	70%	41%	25%	11%	57%	71%	48%	70%	62%	72%	53%	71%
	1970-1989	19%	47%	23%	49%	33%	21%	13%	32%	52%	27%	48%	35%	53%	31%	50%
Mixed-Humid	Before 1950	55%	86%	62%	86%	50%	28%	10%	66%	86%	55%	86%	72%	86%	61%	86%
	1950-1969	46%	84%	54%	84%	48%	28%	10%	59%	84%	49%	85%	66%	84%	56%	85%
	1970-1989	17%	58%	22%	60%	47%	27%	13%	33%	65%	27%	55%	37%	66%	30%	57%
Marine	Before 1950	27%	89%	33%	88%	30%	9%	4%	30%	84%	23%	83%	36%	84%	29%	83%
	1950-1969	20%	84%	26%	82%	26%	8%	4%	22%	78%	18%	76%	28%	77%	22%	75%
	1970-1989	9%	50%	13%	51%	25%	7%	5%	12%	51%	9%	45%	15%	51%	12%	47%
Mixed-Dry	Before 1950	30%	83%	38%	83%	47%	18%	13%	40%	80%	30%	79%	46%	81%	36%	80%
	1950-1969	27%	78%	31%	77%	47%	20%	14%	40%	76%	30%	75%	44%	75%	34%	75%
	1970-1989	19%	55%	22%	55%	51%	25%	23%	30%	60%	25%	52%	33%	60%	27%	53%
Hot-Dry	Before 1950	15%	73%	20%	71%	27%	7%	5%	19%	66%	14%	62%	24%	65%	18%	61%
	1950-1969	16%	72%	21%	70%	36%	10%	5%	22%	68%	15%	63%	27%	66%	19%	62%
	1970-1989	7%	42%	10%	41%	48%	15%	9%	15%	51%	10%	35%	18%	49%	12%	36%
Hot-Humid	Before 1950	26%	76%	33%	75%	64%	24%	4%	45%	75%	28%	61%	51%	75%	34%	64%
	1950-1969	14%	62%	19%	61%	65%	23%	3%	38%	63%	21%	48%	42%	62%	25%	49%
	1970-1989	3%	27%	5%	27%	68%	25%	5%	31%	39%	14%	22%	32%	37%	15%	23%

Figure A-11. Percent of eligible homes for each retrofit case in each ungrouped climate zone and vintage range where the SPP is positive and less than 30 years. This is an expanded version of Figure 12.

Building America Ungrouped Climate Zones	Vintage	1″ insulation: Existing	1″ insulation: Re-siding	2″ insulation: Existing	2″ insulation: Re-siding	Storm windows: Existing	Triple pane windows: Existing	Triple pane windows: Code windows	1″ insulation + storm windows: Existing	1″ insulation + storm windows: Re-siding	1″ insulation + triple pane windows: Existing	1″ insulation + triple pane windows: Re-Siding + Code windows	2″ insulation + storm windows: Existing	2″ insulation + storm windows: Re-siding	2″ insulation + triple pane windows: Existing	2″ insulation + triple pane windows: Re-Siding + Code windows
Very Cold	Before 1950	45%	73%	50%	74%	94%	58%	41%	55%	82%	48%	68%	59%	81%	51%	68%
	1950-1969	33%	58%	37%	59%	91%	56%	38%	45%	70%	39%	54%	48%	70%	42%	56%
	1970-1989	29%	60%	36%	61%	90%	63%	47%	43%	67%	38%	59%	47%	67%	43%	59%
Cold	Before 1950	41%	92%	47%	91%	81%	33%	12%	48%	92%	37%	80%	53%	92%	41%	80%
	1950-1969	32%	87%	38%	86%	79%	30%	9%	41%	87%	30%	73%	45%	87%	34%	73%
	1970-1989	10%	42%	14%	44%	77%	34%	17%	22%	47%	15%	37%	25%	48%	18%	39%
Mixed-Humid	Before 1950	31%	99%	38%	98%	77%	26%	3%	38%	96%	28%	81%	44%	96%	33%	82%
	1950-1969	24%	98%	30%	98%	78%	25%	4%	32%	96%	23%	80%	38%	96%	27%	81%
	1970-1989	7%	48%	10%	50%	78%	24%	6%	17%	55%	10%	38%	20%	55%	12%	40%
Marine	Before 1950	11%	79%	15%	77%	32%	6%	0%	13%	71%	9%	66%	16%	70%	12%	65%
	1950-1969	7%	71%	10%	67%	27%	4%	1%	9%	61%	6%	57%	11%	60%	8%	56%
	1970-1989	3%	33%	4%	32%	27%	4%	1%	4%	31%	3%	27%	5%	30%	4%	27%
Mixed-Dry	Before 1950	18%	83%	26%	81%	50%	17%	8%	24%	77%	18%	63%	30%	77%	23%	64%
	1950-1969	19%	84%	23%	82%	48%	16%	10%	26%	79%	17%	62%	28%	77%	19%	61%
	1970-1989	13%	49%	16%	49%	50%	20%	17%	20%	48%	13%	39%	22%	48%	15%	40%
Hot-Dry	Before 1950	6%	58%	9%	55%	25%	4%	2%	7%	49%	5%	43%	10%	48%	7%	42%
	1950-1969	6%	61%	8%	58%	33%	4%	3%	8%	53%	5%	44%	10%	52%	6%	44%
	1970-1989	3%	28%	4%	27%	46%	5%	4%	6%	32%	3%	20%	7%	30%	3%	21%
Hot-Humid	Before 1950	10%	80%	14%	77%	58%	9%	0%	20%	75%	8%	43%	23%	73%	10%	44%
	1950-1969	4%	69%	6%	66%	55%	7%	0%	18%	66%	5%	33%	20%	64%	6%	34%
	1970-1989	1%	26%	1%	25%	61%	8%	1%	20%	32%	3%	11%	20%	30%	3%	12%

Upgrade Run / Reference Run

Figure A-12. Percent of eligible homes in each ungrouped climate zone and vintage range where the retrofit case has a positive NPV, for each retrofit case in the analysis. This is an expanded version of Figure 14.

Appendix B. Results of Reference Scenarios Versus Baseline

This appendix presents the same results graphics used for the upgrade scenarios versus the reference scenarios, but for the reference scenarios versus baseline. All the histograms use the same bin sizes and under/overflow bin definitions as were used in the parallel graphics in the main body of this report.

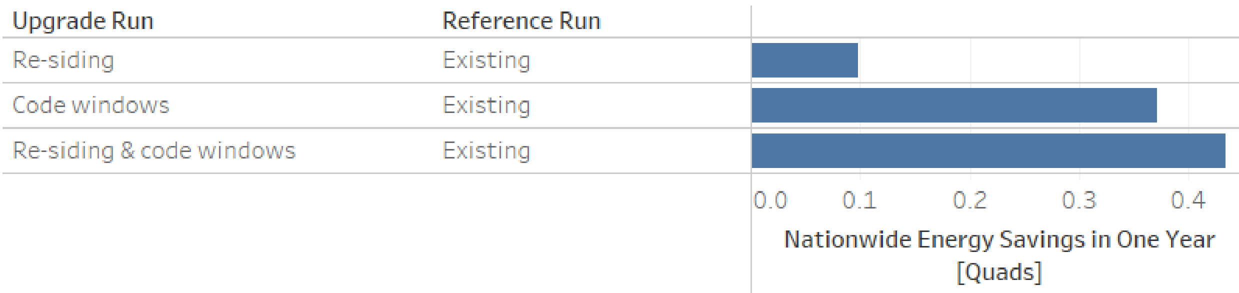

Figure B-1. Total one-year nationwide energy savings if every house represented in the analysis were to have the specified reference case implemented.

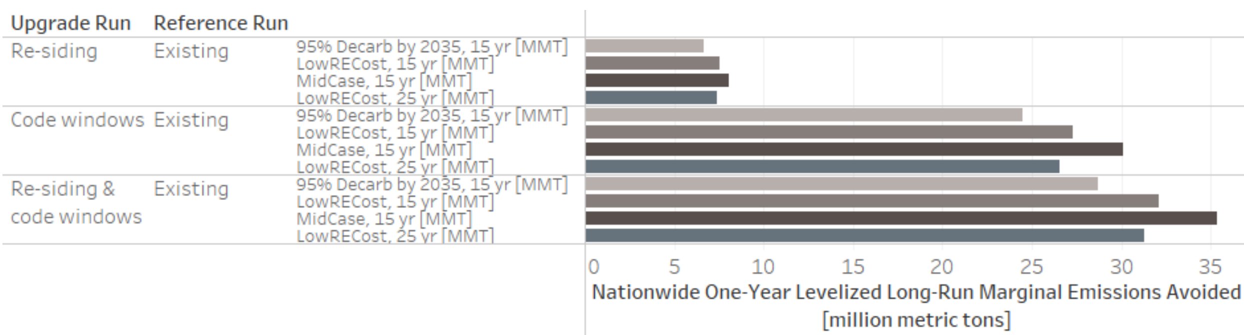

Figure B-2. Total one-year nationwide carbon emissions reduction if every house represented in the analysis were to have the specified reference case implemented.

		Upgrade Run / Reference Run		
		Re-siding	Code windows	Re-siding & code windows
Building America Climate Zone	Vintage	Existing	Existing	Existing
Cold & Very Cold	Before 1950	4.7 (σ12.3)	26.0 (σ18.0)	16.8 (σ21.9)
	1950-1969	3.5 (σ10.3)	21.7 (σ14.8)	13.1 (σ18.1)
	1970-1989	5.8 (σ7.0)	20.7 (σ14.6)	13.4 (σ15.3)
Mixed-Humid	Before 1950	3.1 (σ9.7)	19.0 (σ15.1)	12.4 (σ17.7)
	1950-1969	1.3 (σ7.8)	15.4 (σ12.1)	8.8 (σ13.8)
	1970-1989	2.9 (σ5.9)	12.9 (σ10.3)	8.9 (σ11.3)
Marine	Before 1950	-1.4 (σ7.5)	8.7 (σ8.8)	2.8 (σ10.4)
	1950-1969	-0.8 (σ6.1)	6.3 (σ7.2)	2.3 (σ8.5)
	1970-1989	0.7 (σ4.7)	6.3 (σ7.1)	3.6 (σ7.4)
Hot-Dry & Mixed-Dry	Before 1950	-1.2 (σ5.2)	5.1 (σ6.0)	1.7 (σ7.1)
	1950-1969	-0.2 (σ4.4)	5.0 (σ5.7)	2.8 (σ6.8)
	1970-1989	1.2 (σ3.1)	5.5 (σ5.7)	4.8 (σ6.5)
Hot-Humid	Before 1950	0.8 (σ4.0)	8.6 (σ6.3)	6.8 (σ7.4)
	1950-1969	0.3 (σ3.3)	7.4 (σ5.7)	5.8 (σ6.5)
	1970-1989	1.3 (σ2.6)	7.6 (σ5.8)	7.0 (σ6.4)

Figure B-3. Average (mean) and standard deviation (σ) of annual site energy savings (MMBtu/year) for the reference scenarios aggregated by climate zone and vintage range.

		Upgrade Run / Reference Run		
		Re-siding	Code windows	Re-siding & code windows
Building America Climate Zone	Vintage	Existing	Existing	Existing
Cold & Very Cold	Before 1950	3.6% (σ5.5%)	12.5% (σ4.4%)	7.2% (σ8.4%)
	1950-1969	3.0% (σ5.2%)	11.5% (σ4.3%)	6.3% (σ8.0%)
	1970-1989	3.6% (σ3.3%)	12.2% (σ4.9%)	6.5% (σ7.0%)
Mixed-Humid	Before 1950	2.0% (σ5.1%)	11.1% (σ4.4%)	6.4% (σ7.8%)
	1950-1969	0.1% (σ4.7%)	10.1% (σ4.2%)	5.1% (σ7.2%)
	1970-1989	2.4% (σ3.7%)	9.9% (σ4.7%)	6.0% (σ6.7%)
Marine	Before 1950	-1.5% (σ6.4%)	7.3% (σ4.7%)	2.3% (σ7.9%)
	1950-1969	1.1% (σ5.7%)	5.6% (σ4.4%)	2.4% (σ7.1%)
	1970-1989	1.3% (σ4.3%)	5.7% (σ5.3%)	3.0% (σ6.3%)
Hot-Dry & Mixed-Dry	Before 1950	0.4% (σ6.0%)	5.1% (σ4.0%)	1.9% (σ7.1%)
	1950-1969	1.1% (σ5.1%)	4.9% (σ4.1%)	2.8% (σ6.5%)
	1970-1989	1.5% (σ3.0%)	5.6% (σ4.5%)	4.6% (σ5.7%)
Hot-Humid	Before 1950	1.4% (σ3.6%)	8.4% (σ3.7%)	7.0% (σ5.9%)
	1950-1969	0.9% (σ3.3%)	7.9% (σ3.7%)	6.7% (σ5.5%)
	1970-1989	1.8% (σ2.6%)	8.6% (σ4.2%)	8.2% (σ5.5%)

Figure B-4. Average (mean) and standard deviation of percent site energy savings for each reference scenario compared to the existing building stock (baseline reference scenario), aggregated by climate zone and vintage range.

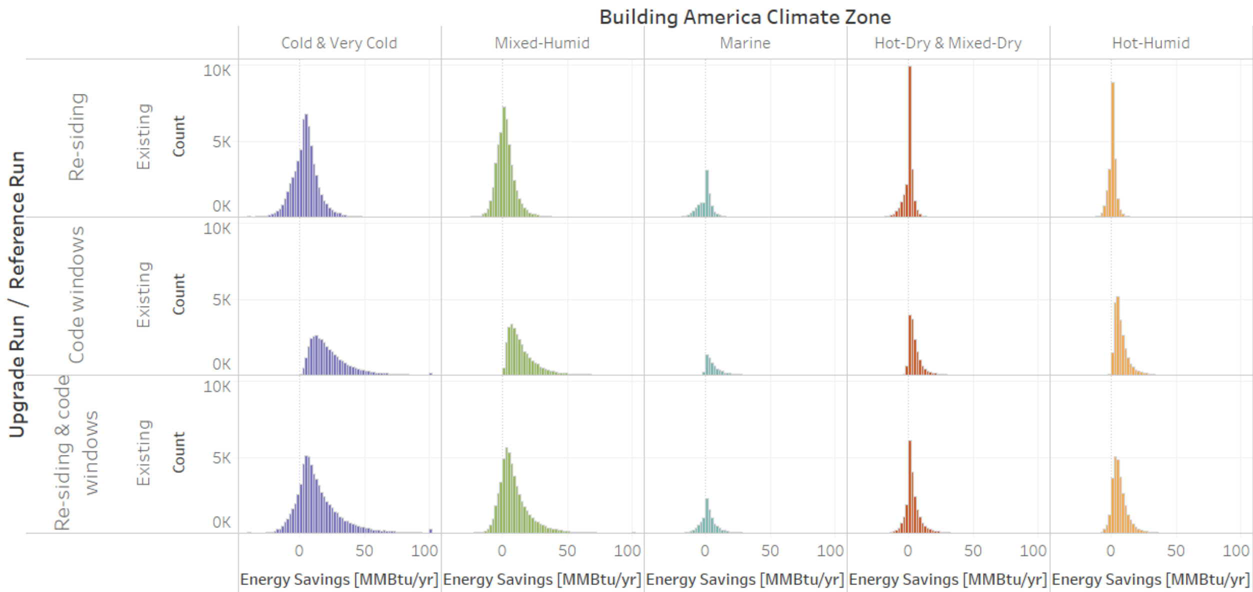

Figure B-5. Distributions of annual site energy savings (MMBtu/year) for the reference scenarios, separated by climate zone. The histograms have a bin size of 2 MMBtu/year, an overflow bin for values 100 MMBtu/year and over, and an underflow bin for values below -40 MMBtu/year. Negative values indicate an increase in energy use.

		Upgrade Run / Reference Run		
		Re-siding	Code windows	Re-siding & code windows
Building America Climate Zone	Vintage	Existing	Existing	Existing
Cold & Very Cold	Before 1950	$78 (σ214)	$399 (σ377)	$262 (σ403)
	1950-1969	$55 (σ175)	$317 (σ303)	$196 (σ319)
	1970-1989	$101 (σ142)	$360 (σ335)	$235 (σ316)
Mixed-Humid	Before 1950	$55 (σ175)	$328 (σ285)	$217 (σ319)
	1950-1969	$30 (σ142)	$288 (σ249)	$170 (σ264)
	1970-1989	$64 (σ124)	$289 (σ238)	$202 (σ253)
Marine	Before 1950	$-25 (σ141)	$153 (σ179)	$50 (σ197)
	1950-1969	$-11 (σ114)	$118 (σ133)	$48 (σ161)
	1970-1989	$12 (σ85)	$125 (σ143)	$71 (σ144)
Hot-Dry & Mixed-Dry	Before 1950	$-13 (σ122)	$128 (σ157)	$63 (σ181)
	1950-1969	$8 (σ100)	$138 (σ157)	$93 (σ179)
	1970-1989	$33 (σ79)	$177 (σ188)	$152 (σ204)
Hot-Humid	Before 1950	$32 (σ93)	$217 (σ169)	$184 (σ191)
	1950-1969	$24 (σ77)	$191 (σ139)	$167 (σ161)
	1970-1989	$44 (σ68)	$215 (σ156)	$204 (σ175)

Figure B-6. Average (mean) and standard deviation (σ) of annual bill savings ($/year) for reference scenario, aggregated by climate zone and vintage range.

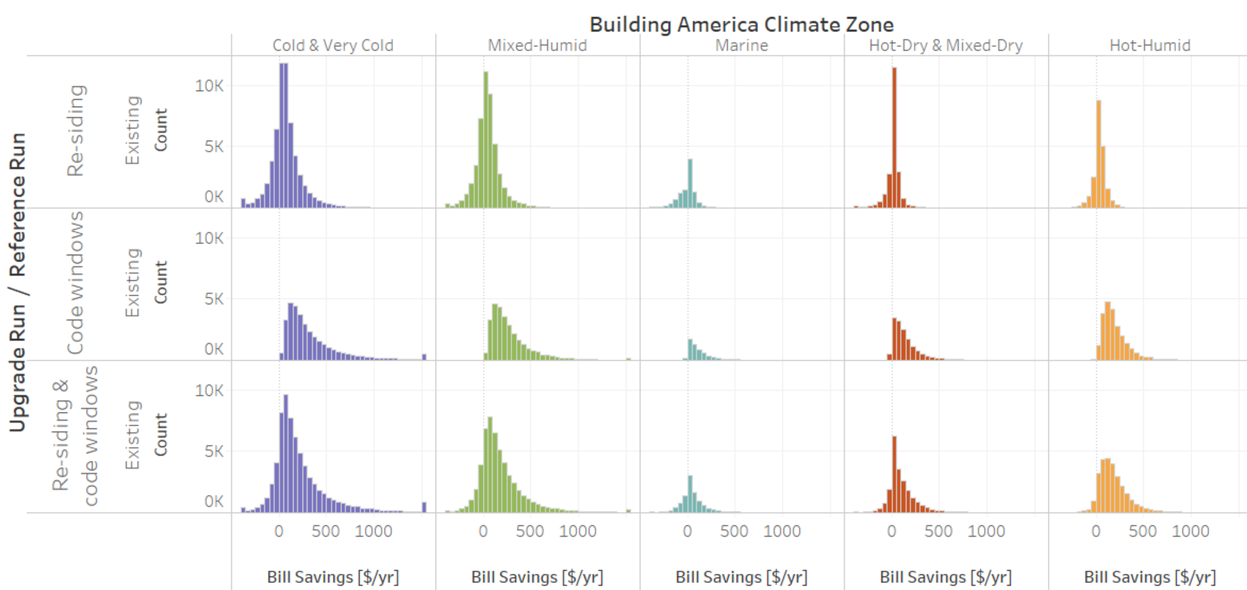

Figure B-7. Distributions of annual bill savings ($/year) for each retrofit case in the analysis, separated by climate zone. The histograms use a bin size of $50, an overflow bin for values $1,500 or higher, and an underflow bin for values -$400 or below.

Building America Climate Zone	Vintage	Upgrade Run / Reference Run: Re-siding (Existing)	Upgrade Run / Reference Run: Code windows (Existing)	Upgrade Run / Reference Run: Re-siding & code windows (Existing)
Cold & Very Cold	Before 1950	14%	32%	25%
	1950-1969	10%	28%	21%
	1970-1989	9%	23%	20%
Mixed-Humid	Before 1950	10%	34%	19%
	1950-1969	6%	33%	16%
	1970-1989	4%	32%	15%
Marine	Before 1950	2%	11%	4%
	1950-1969	1%	9%	2%
	1970-1989	1%	8%	2%
Hot-Dry & Mixed-Dry	Before 1950	1%	10%	2%
	1950-1969	0%	14%	3%
	1970-1989	1%	22%	4%
Hot-Humid	Before 1950	2%	41%	13%
	1950-1969	0%	41%	14%
	1970-1989	0%	43%	18%

Figure B-8. Percent of eligible homes for each retrofit case and reference scenario in each climate zone and vintage range where the SPP is positive and less than 30 years.

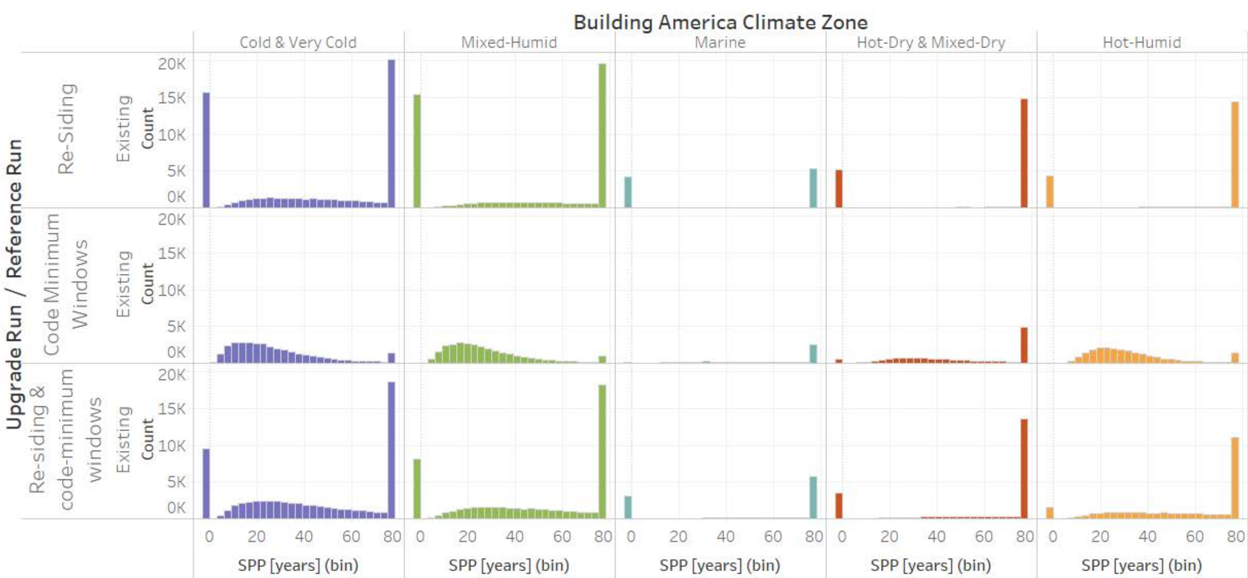

Figure B-9. Distributions of simple payback period (years) for each retrofit case included in the analysis, separated by climate zone. The histograms have a bin size of 3 years with an overflow bin for 75 years and above, and an underflow bin for 0 years and below.

		Upgrade Run / Reference Run		
		Re-siding	Code windows	Re-siding & code windows
Building America Climate Zone	Vintage	Existing	Existing	Existing
Cold & Very Cold	Before 1950	$-8,402, $-2,676	$-3,158, $2,026	$-9,295, $-2,203
	1950-1969	$-8,566, $-2,936	$-2,801, $1,245	$-9,021, $-2,352
	1970-1989	$-8,763, $-3,535	$-3,037, $1,903	$-9,178, $-2,699
Mixed-Humid	Before 1950	$-9,434, $-3,445	$-3,039, $1,146	$-10,408, $-3,260
	1950-1969	$-10,260, $-4,094	$-2,536, $925	$-10,818, $-3,623
	1970-1989	$-10,781, $-4,961	$-2,759, $745	$-11,308, $-4,244
Marine	Before 1950	$-10,506, $-5,189	$-6,626, $-2,312	$-13,977, $-6,463
	1950-1969	$-10,770, $-5,931	$-6,265, $-2,408	$-14,195, $-7,211
	1970-1989	$-11,121, $-5,912	$-6,654, $-2,630	$-14,217, $-7,081
Hot-Dry & Mixed-Dry	Before 1950	$-10,529, $-6,037	$-6,280, $-2,340	$-14,359, $-7,317
	1950-1969	$-10,902, $-6,333	$-5,287, $-1,938	$-13,941, $-7,363
	1970-1989	$-11,722, $-6,765	$-5,144, $-1,528	$-14,948, $-7,562
Hot-Humid	Before 1950	$-9,276, $-4,551	$-2,948, $-192	$-10,505, $-4,409
	1950-1969	$-10,680, $-5,690	$-2,805, $-316	$-11,410, $-3,983
	1970-1989	$-12,127, $-7,004	$-2,858, $-267	$-12,373, $-3,122

Figure B-10. First and third quartile of NPV ($) for each retrofit case included in the analysis, aggregated by climate zone and vintage range.

		Upgrade Run / Reference Run		
		Re-siding	Code windows	Re-siding & code windows
Building America Climate Zone	Vintage	Existing	Existing	Existing
Cold & Very Cold	Before 1950	8%	39%	14%
	1950-1969	5%	36%	11%
	1970-1989	5%	39%	12%
Mixed-Humid	Before 1950	4%	35%	9%
	1950-1969	3%	36%	7%
	1970-1989	1%	33%	6%
Marine	Before 1950	0%	8%	1%
	1950-1969	0%	5%	1%
	1970-1989	0%	5%	0%
Hot-Dry & Mixed-Dry	Before 1950	0%	6%	1%
	1950-1969	0%	6%	1%
	1970-1989	0%	9%	1%
Hot-Humid	Before 1950	0%	22%	4%
	1950-1969	0%	20%	5%
	1970-1989	0%	21%	7%

Figure B-11. Percent of eligible homes in each climate zone and vintage range where the upgrade has a positive NPV, for each retrofit case in the analysis.

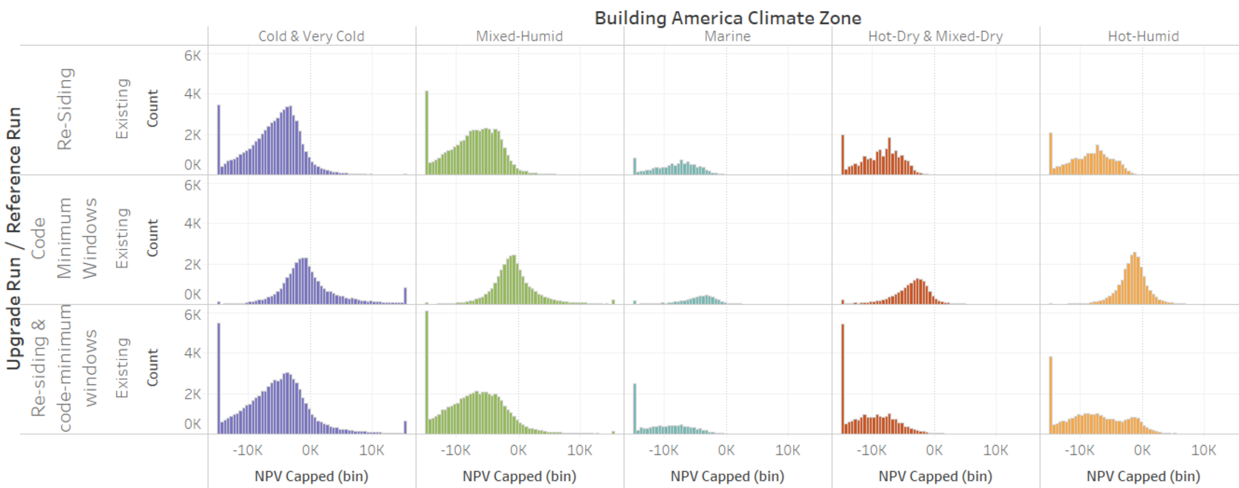

Figure B-12. Distributions of NPV ($) for each retrofit case and reference scenario, separated by climate zone. The histograms use a bin size of $1,000, an overflow bin for $15,000 and higher, and an underflow bin for -$15,000 and lower.