Evaluation of Under Insulated Single-Family Detached Homes in the United States

Submitted to:
North American Insulation Manufacturers Association

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Background and Objectives

The objective of this study was to estimate the percentage of single-family detached homes that do not meet the IECC 2012 insulation standards, thereby providing North American Insulation Manufacturers (NAIMA) with a high-level overview of insulation levels across the nation and the opportunity to inform future insulation practices and policies.

The decision to use the IECC 2012 insulation standard as a baseline was driven by the fact that, at the time of this study, 22 out of the 50 U.S. states have adopted residential code efficiency standards categorized as equivalent to IECC 2012 or higher[1]. Therefore, the IECC 2012 standard allows for a suitable comparison of insulation practices across the nation as it is both achievable and practical.

To execute this study, ICF utilized the National Renewable Energy Laboratory (NREL) ResStock database[2]. This tool employs statistical sampling utilizing a robust methodology to create extensive datasets of building energy models that are representative of the existing residential buildings across the United States. Each model contains over 250 parameters of its building characteristics, including geographical areas, building geometries, insulation types, floor areas, and more. ResStock statistically represents housing stock characteristics with 6,000 conditional probability distributions derived from several data sources including Residential Energy Consumption Survey (RECS) and US Census data.[3] Dependencies can exist between the various building characteristics, and the data can be organized hierarchically to define these dependencies. For example, the interdependencies of certain building geometry characteristics (floor area, foundation type, and number of stories) are shown in Exhibit 1. The probability distribution for number of stories depends directly on vintage, floor area, and foundation type, and indirectly on location (because the vintage, floor area, and foundation distributions depend on location).

Although ICF explored other data sources such as the Residential Energy Consumption Survey (RECS)[4] and U.S. Census data[5], the ResStock database was found to be the most pertinent and comprehensive dataset available for this analysis.

[1] Building Energy Code Program's State Portal: State Portal | Building Energy Codes Program.

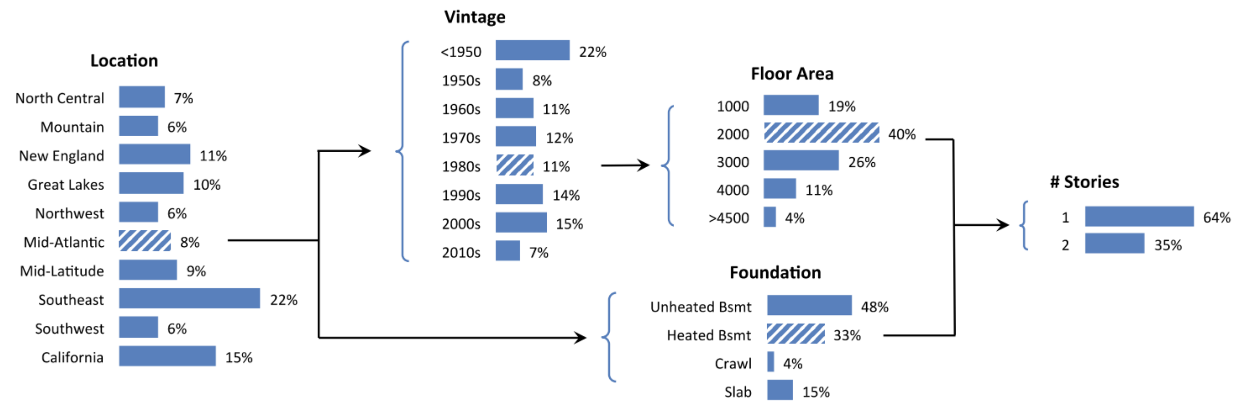
[2] NREL's ResStock page: https://resstock.nrel.gov/.

[3] Wilson, Eric J., Christensen, Craig B., Horowitz, Scott G., Robertson, Joseph J., & Maguire, Jeffrey B. Energy Efficiency Potential in the U.S. Single-Family Housing Stock. United States. https://doi.org/10.2172/1414819

[4] The 2020 RECS microdata was accessed for specific survey responses through: https://resstock.nrel.gov/.

[5] 2023 American Housing Survey (AHS): https://www.census.gov/programs-surveys/ahs/data.html.

Exhibit 1: Probability Distributions of Geometry Characteristics (adapted from [3])



Methodology

The analysis methodology involved the following steps:

1. **Extract IECC 2012 U-factors and ResStock Insulation R-value options:** ICF extracted the maximum assembly U-factors from IECC 2012 for each climate zone, as shown in Table 1. ICF then extracted the option "inputs" from ResStock, mapped them to their given R-value, and converted them to U-factors. By doing so, the two sets of U-factors could be compared directly.

   Sample 1 million single-family detached homes from ResStock: A random sample was taken from the 2024 ResStock public dataset at a national level and filtered by single-family detached homes. The 1-million sample size was selected to account for variations in home characteristics such as age, location, insulation type and is consistent with smaller samples. Previous research was conducted to examine the sensitivity of ResStock outputs to sample size.[3] This study suggested that 200,000 home sample may be sufficient for simulation of the U.S. housing stock, but more qualitative testing of geospatial maps pointed to a more conservative 350,000 sample size. This study tested two sample sizes: 500,000 homes and 1 million homes. The results showed that the statistical analysis was more effective with the 1 million home sample. Appendix B presents the distribution of single-family detached homes by home vintage in the US from the 1 million home sample.
2. **Divide each model into 3 envelope elements:** The envelope of each building model was divided into three key elements: foundation, exterior walls, and roof/ceiling.
3. **Develop an algorithm to compare R-values:** To compare the varying insulation components with the IECC 2012 requirements, an algorithm was developed that follows the appropriate geometry and insulation type of each element. Flow diagrams of these logics can be found in Appendix A.
4. **Define "under insulated" and determine quantity of homes that meet the criteria:** ICF defined a home to be "under insulated" if the sum of thermal conductance (UA) of all three elements from the ResStock sample is greater than that based on IECC 2012 assembly U-factors. Using this definition, ICF quantified the percentage of single-family detached homes considered under insulated.

Table 1: IECC 2012[6] Building Thermal Envelope Maximum Assembly U-factors (adapted from Table R402.1.3 in IECC 2012).

Climate Zone	Ceiling/ Roof	Floor	Foundation Wall	Slab[7]	Wall (Frame)	Wall (Mass)	Crawl Space Wall
1	0.035	0.064	0.36	0	0.082	0.197	0.477
2	0.03	0.064	0.36	0	0.082	0.165	0.477
3	0.03	0.047	0.091	0	0.057	0.098	0.136
4 except Marine	0.026	0.047	0.059	0.1, 2ft.	0.057	0.098	0.065
5 and Marine 4	0.026	0.033	0.05	0.1, 2ft.	0.057	0.082	0.055
6	0.026	0.033	0.05	0.1, 4ft.	0.048	0.06	0.055
7	0.026	0.028	0.05	0.1, 4ft.	0.048	0.057	0.055
8	0.026	0.028	0.05	0.1, 4ft.	0.048	0.057	0.055

Table 2: IECC 2012 Insulation Minimum R-Values by Component (adapted from Table R402.1.1 in IECC 2012).

Climate Zone	Ceiling/Roof	Floor	Foundation Wall	Slab	Wall (Frame)	Wall (Mass)	Crawl Space Wall
1	30	13	0	0	13	3/4	0
2	38	13	0	0	13	4/6	0
3	38	19	5/13*	0	20 or 13+5***	8/13****	5/13*
4 except Marine	49	19	10/13	10, 2ft.**	20 or 13+5	8/13	10/13
5 and Marine 4	49	30	15/19	10, 2ft.	20 or 13+5	13/17	15/19
6	49	30	15/19	10, 4ft.	20+5 or 13+10	15/20	15/19
7	49	38	15/19	10, 4ft.	20+5 or 13+10	19/21	15/19
8	49	38	15/19	10, 4ft.	20+5 or 13+10	19/21	15/19

*** "5/13" means R-5 continuous insulation on the interior or exterior of the home or R-13 cavity insulation at the interior of the wall.**
**** 2 ft. is the depth of slab insulation.**
***** "13+5" means R-13 cavity insulation plus R-5 continuous insulation.**
****** "8/13" for mass wall means that the second number i.e., R-13, applies when more than half the insulation is on the interior of the mass wall.**

The IECC 2012 maximum U-factor requirements for each assembly are outlined in Table R402.1.3[8] except for slab, which is considered a component and therefore outlined in Table R402.1.1[9]. A summary of insulation requirements for both U-factor and R-value are provided in Tables 1 and 2, respectively. An important note to be made about the slab depth requirement is that it was

[6] 2012 International Energy Conservation Code (IECC): https://codes.iccsafe.org/content/IECC2012P5.

[7] First value is the U-factor requirement, second value is the insulation depth requirement.

[8] Table 402.1.3 can be found in Chapter 4 [RE]: 2012 International Energy Conservation Code (IECC) - CHAPTER 4 (iccsafe.org).

[9] Table 402.1.1 can be found in Chapter 4 [RE]: 2012 International Energy Conservation Code (IECC) - CHAPTER 4 (iccsafe.org).

ignored for the purpose of this study, though a short preliminary analysis found that less than 0.2% of the overall results were impacted by discrepancies in slab depths.

Results

This section demonstrates the results for the whole home and for the individual envelope elements.

Whole Home Insulation

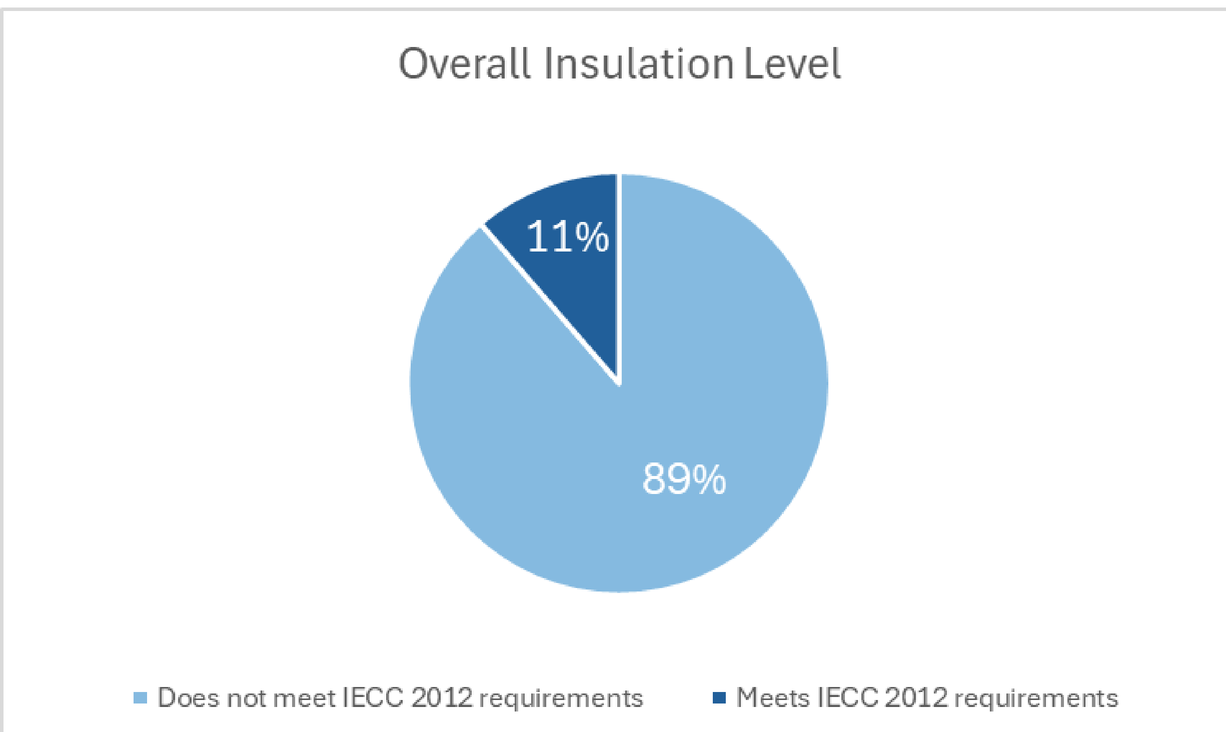
ICF defined "overall insulation" as the sum of each building envelope element's UA, which represents the product of the U-factor of each given element and its surface area, as shown in the following equation:

$$\Sigma UA = U\_wall \times A\_wall + U\_ceiling \times A\_ceiling + U\_foundation \times A\_foundation$$

A home is therefore considered 'under insulated' if its total UA is larger than that of the total UA calculated using IECC 2012 assembly U-factors. This allows a highly insulated envelope element to compensate for other under insulated elements, maintaining overall thermal performance.

The analysis reveals that approximately 89% of single-family detached homes are under insulated when compared to the 2012 IECC requirements, as shown in Exhibit 2.

Exhibit 2: Distribution of Under Insulated SF Detached Homes in the US for a 1 Million Sample Size.

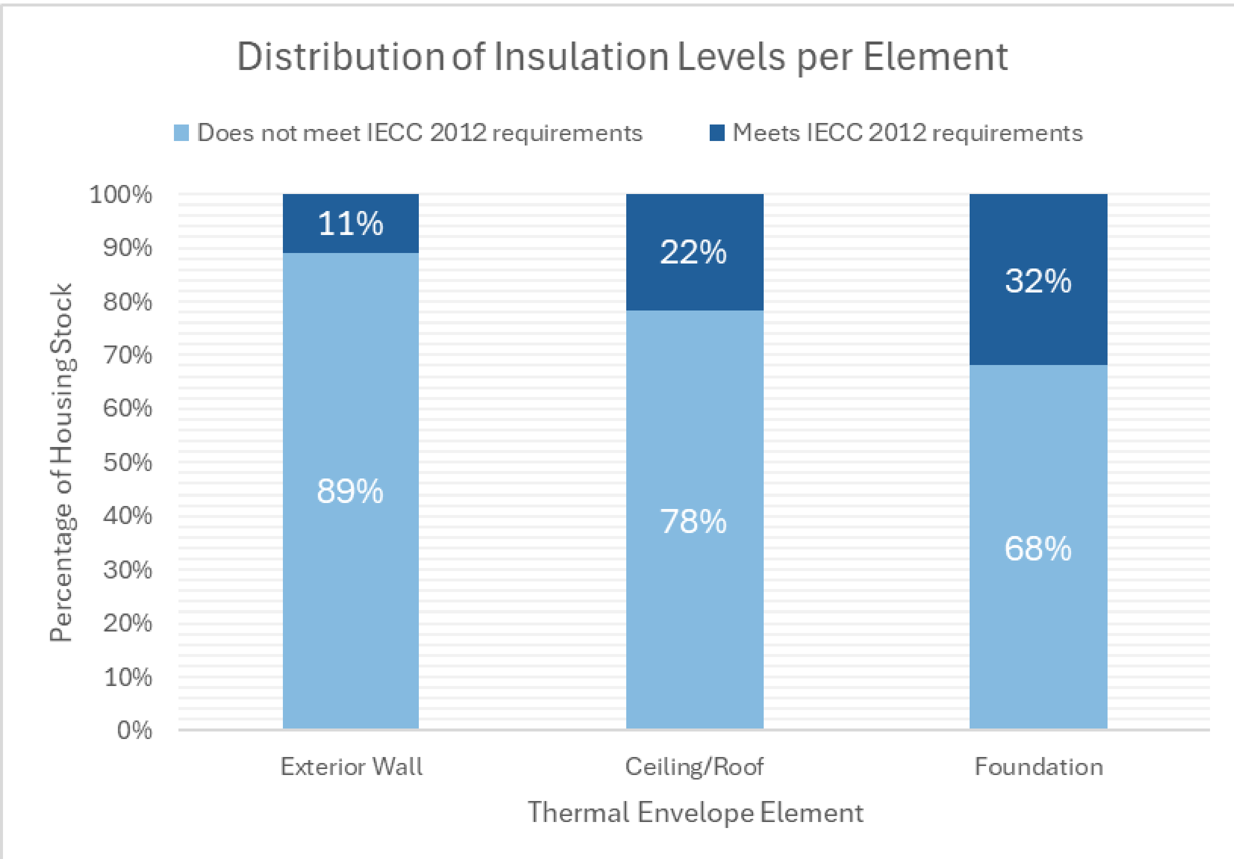


The results of this study may vary by geographical area, as home archetypes differ from region to region. For a more detailed analysis of the distribution of home archetypes, the ResStock database provides a granular breakdown by climate zone, state, and other relevant factors.

Insulation by Envelope Element

The analysis indicated varying proportions of under insulated envelope elements across the nation. As demonstrated in Exhibit 3, 89% of exterior walls, 78% of ceilings, and 68% of foundations (e.g. floors, slab edge, crawl space, basement walls) in single-family homes across the nation were found to be under insulated when compared to IECC 2012 requirements. It is worth noting that the IECC 2012 does not require insulation on the foundation elements in climate zones 1 and 2. As such, all homes in these climate zones are considered code compliant on the foundation insulation requirements. This explains the larger portion of homes that meet the IECC 2012 insulation requirements for the foundation elements.

Exhibit 3: Distribution of Under Insulated Building Envelope Elements for a 1 Million Sample Size



According to the 2023 American Housing Survey[10], there are approximately 85.26 million single-family detached homes in the United States. By applying this figure to the percentages presented in Exhibits 2 and 3, we can estimate the number of homes that meet and do not meet the IECC 2012 insulation requirements. Table 3 summarizes the proportions of single

[10] 2023 American Housing Survey (AHS): https://www.census.gov/programs-surveys/ahs/data.html.

family homes that meet the IECC 2012 insulation requirements for individual envelope elements as well as for the entire home.

Table 3: Summary of Quantity of Single-Family Detached Homes that Meet and Do Not Meet IECC 2012 Requirements.

Thermal Envelope Element	**Do not meet IECC 2012**		**Meets IECC 2012**	
	Number of Homes	Percentage	Number of Homes	Percentage
Exterior Wall	75.83 million	89%	9.37 million	11%
Ceiling/Roof	66.46 million	78%	18.74 million	22%
Foundation	57.94 million	68%	27.26 million	32%
Overall	**75.83 million**	**89%**	**9.37 million**	**11%**

The ResStock dataset presented certain limitations, particularly regarding the component areas of the building envelope provided. For models with an 'Ambient' foundation, the dataset recorded the foundation areas as zero, posing a significant issue for calculating UA. To address this, the roof area was used as a substitute for these calculations. While the roof area does not exactly reflect the floor area for an 'Ambient' foundation, ICF determined that this substitution only resulted in a deviation of 0.1% when compared to a sample without 'Ambient' foundations.

Conclusions

This study was conducted using the ResStock database to identify the percentage of homes that have insulation levels that do not meet or exceed the 2012 IECC requirements. The findings emphasize the overwhelming prevalence of under insulated homes in the United States. Around 89% of the US single family detached housing stock is under insulated when compared to 2012 IECC baseline.

Appendix A

Exhibits A-C present the flow diagrams for comparing R-values between ResStock data and IECC 2012 requirements for exterior wall, roof/ceiling, and foundation insulation, respectively.[11]

Exhibit A: Flow diagram for comparing ResStock Exterior Wall Insulation R-values with 2012 IECC R-values.

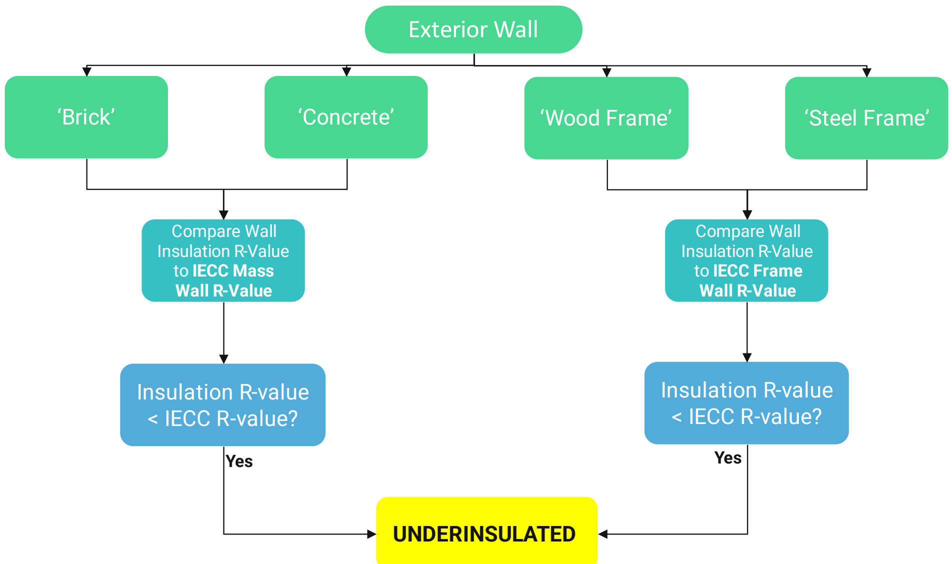
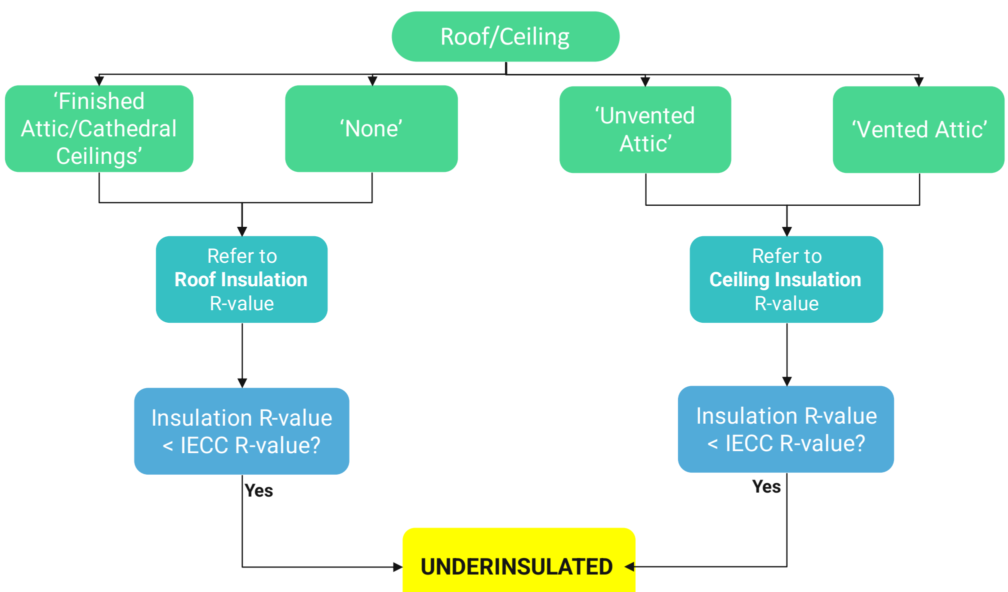
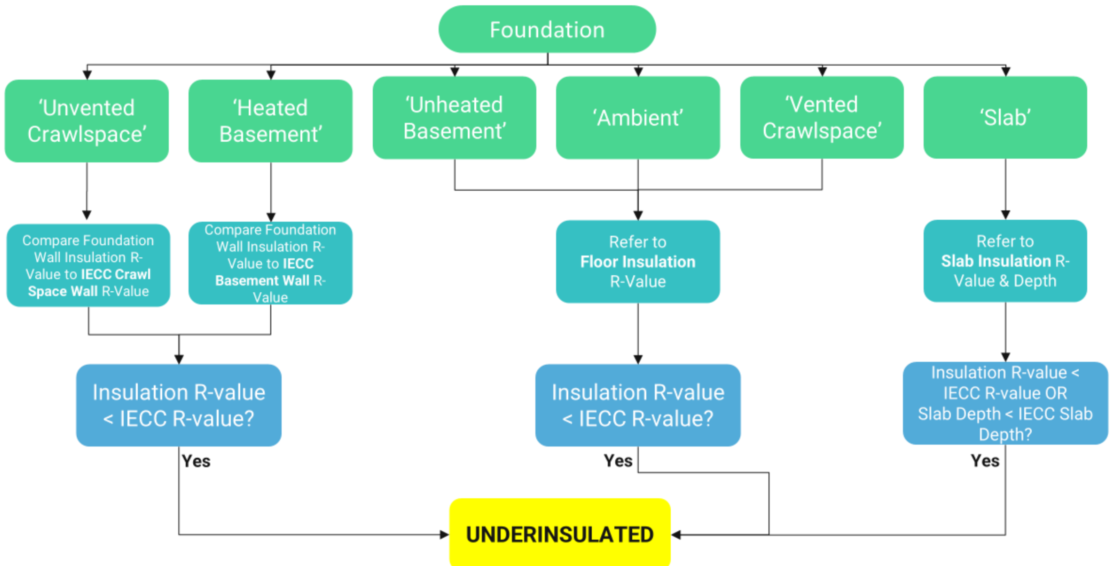


Exhibit B: Flow diagram for comparing ResStock Roof/Ceiling Insulation R-values with 2012 IECC R-values.



[11] The flowcharts do not include a path for "No's" because they are set up to identify if a home's specific element is "under insulated" based on its R-value.

Exhibit C: Flow diagram for comparing ResStock Foundation Insulation R-values with 2012 IECC R-values.



Appendix B

Exhibit D shows the breakdown of percentage of single-family detached homes by home vintage in the nation. This distribution supports the study in understanding insulation levels across the country, as building codes and insulation standards have evolved significantly over time.

Exhibit D: Breakdown of the percentage of single-family detached homes by home vintages.