Residential Energy Code Field Studies: Assessing Implementation in Seven States

September 2022

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Executive Summary

Beginning in 2014, the U.S. Department Energy (DOE) funded a series of multi-year residential energy code field studies to explore energy savings opportunities from enhanced code compliance. The project's primary goals were to: (1) establish a standardized methodology to quantify the energy impacts of code-based measures in single-family residential construction; (2) test whether compliance could be improved through education, training, and outreach activities; and (3) project the long-term savings from enhanced energy code compliance. A complete methodology was developed and successfully implemented in seven pilot states funded by DOE. The study was broken into three phases:

> **Phase I:** A baseline field study to assess the energy performance of newly constructed single-family residential buildings in a given state and identify opportunities for energy efficiency improvements;
>
> **Phase II:** Education, training, and outreach activities targeting code compliance issues identified from the baseline study;
>
> **Phase III:** A second field study to measure the impact of the Phase II training activities on code compliance and the associated energy impacts.

Following the baseline studies (i.e., Phase I), teams spent approximately 2 years implementing a variety of training intervention strategies customized for each state (i.e., Phase II). Strategies were not specified by DOE, but instead selected by each project team based on state needs. The most common strategies included classroom training, online training, use of circuit riders (individuals with subject matter expertise who mobilize to serve multiple jurisdictions across a given geographic area), hotlines, and various types of technical resources. A second field study (i.e., Phase III) was then conducted to compare results to the original baseline study.

This report presents the final results across the three phases to assess whether the education and training activities successfully improved code compliance to achieve significant changes in energy use. When the studies began, most states were on some version of the 2009 International Energy Conservation Code (IECC) with one state on the 2015 IECC. By the end of the field studies, most states had adopted some version of the 2015 IECC. The DOE pilots identified over $18 million in estimated annual savings available from baseline studies through increased compliance with state codes already in place.

Methodology

The project applied a new methodology developed by the Pacific Northwest National Laboratory (PNNL) for the DOE's Building Energy Codes Program (BECP). The methodology facilitates a consistent and replicable approach towards code compliance studies that produces transparent data on construction practices across U.S. states. Compared to previous studies, this new methodology offers a more flexible sampling design to evaluate code compliance centered on an energy metric.

Project teams applied the prescribed DOE methodology based on collecting construction data on energy code-required building components with the largest direct impact on energy consumption. These *key items* were a focal point of the study, and in turn, drove the analysis and savings estimates. The project teams implemented customized sampling plans representative of new construction for each pilot state. Plans were then vetted with key state stakeholders through a series of public meetings.

Following each data collection phase, PNNL conducted three stages of analysis on the resulting data set (Figure ES.1.1). The first stage identified compliance trends within the state based on the distributions observed in the field for each key item. The second modeled energy consumption of the homes observed in the field relative to what would be expected if sampled homes just met minimum code requirements. The third stage then calculated results based on three metrics emphasized by states as of interest relative to tracking code implementation status—potential energy savings, consumer cost savings, and environmental impacts associated with increased code compliance. Together, these findings provide valuable insight about ongoing challenges facing energy code implementation and enforcement.

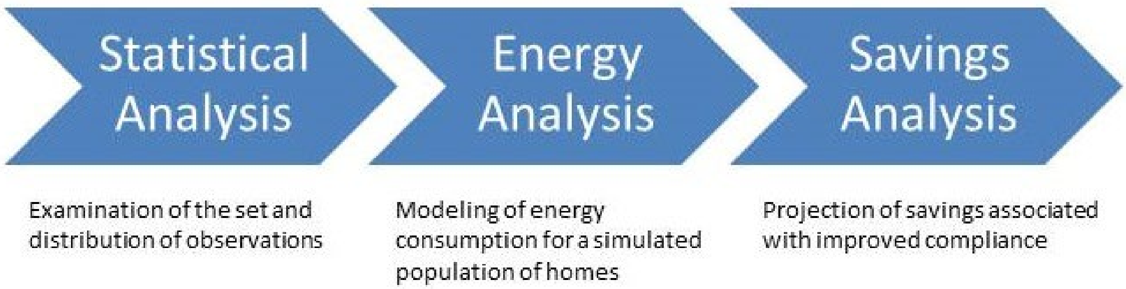

Figure ES.1.1 Stages of Analysis Applied in the Study

Success for the study is characterized by: (1) a measurable decrease in estimated statewide energy use and (2) a reduction in estimated measure-level savings potential between Phases I and III. To estimate average statewide energy consumption, field data were analyzed to calculate average statewide energy use as characterized by EUI. Field observations from Phase I and Phase III were analyzed independently and compared to a scenario based on the state energy code's minimum prescriptive requirements. The Phase III results were then compared to the Phase I results to determine whether a measurable change could be detected.

Next, the field data were assessed from the perspective of individual energy efficiency measures, or the key items with the greatest potential for savings in the state. The savings figures represent the potential annual savings associated with each observable measure compared to a counterfactual scenario where all observations meet the prescriptive code requirement. The statistical trends were then extrapolated based on projected new construction across each state. These items, as identified in the Phase I baseline field study, were targeted as a focal point for Phase II education and training activities, and then reassessed following the Phase III study to examine whether a measurable change was detected. Improvement is achieved through a *reduction* in measure-level savings potential between Phases I and III.

Results from the energy analysis were also aggregated to calculate an average statewide energy use intensity (EUI) weighted by all observed compliance measures. The calculated EUI for Phase I and III offers a consistent metric to determine whether code compliance training and education yielded a measurable improvement in the energy performance of new single-family homes.

FINDINGS

Phase I data exhibited a large variation in compliance rates across key measures. Overall, statewide EUIs were lower than project team expectations. Window requirements, both U-factor and solar heat gain coefficient (SHGC), were almost universally met or exceeded. On the other hand, lighting compliance performed worse. Insulation installation quality (IIQ) was also an issue across states, which highlighted the need to address several aspects of insulation requirements. R-value insulation compliance looked good overall, with most observations occurring right at the requirement level, but U-factor compliance did not. Given the mixed compliance trends, there was still room for further energy savings.

Performance testing of the duct system and building envelope uncovered some unexpected findings. The methodology required that all duct systems be tested regardless of whether they were in conditioned space. Even though all ducts are to be sealed, interestingly, ducts in conditioned space (about 20% of the total duct observations) tended to be leakier than those in unconditioned space, particularly in states with less stringent tightness requirements. Another interesting trend was that tested homes had a much tighter building envelope than expected, with an average air tightness rate of 4.5 ACH50. A tight building envelope was even true in states where the code did not require testing. On the flip side, well-sealed building envelopes raise concerns about adequate ventilation. While there was insufficient information to fully assess mechanical ventilation requirements, the collected data indicates 70% of homes only had a bath fan installed. This finding raises concerns about inadequate ventilation and necessitates further investigation.

Phase III showed an improvement in key measure compliance rates within most states. This resulted in a reduction in the average EUI across five of the seven states, with four states achieving improvements that are considered statistically significant. Compliance rates for high-efficacy lighting significantly increased across all states. Frame wall insulation (U-factor) had greater compliance in all but one state, yet there was still room for additional savings. Ceiling insulation (U-factor) compliance improved in all but two states, primarily driven by better IIQ.

Between Phase I and III, the observed increase in code compliance resulted in a combined energy savings of over $8 million (Table ES.1.1), indicating the positive impacts of energy code education and training. Despite this success, an estimated $10.6 million in potential savings remains after Phase III, which could be captured through further energy code compliance.

Table ES.1.1 Summary of Annual Statewide Energy Cost Savings

State	Annual Potential Savings		Statewide Savings Achieved from Phase II (Phase I – Phase III)	
	Phase I	Phase III	Annual Energy Cost Savings	% Change
Pennsylvania	$3,198,846	$3,013,497	$185,349	5.8%
Maryland	$1,542,788	$311,414	$1,231,374	79.8%
Kentucky	$1,219,856	$928,586	$291,270	23.9%
North Carolina	$2,025,958	$2,368,044	-$342,086	-16.9%
Georgia	$4,516,678	$1,751,143	$2,765,535	61.2%
Alabama	$1,299,382	$978,585	$320,797	24.7%
Texas	$4,847,797	$1,243,958	$3,603,839	74.3%
Total	**$18,651,305**	**$10,595,227**	**$8,056,078**	**43.2%**

In summary, the project demonstrates the lasting energy, economic, and environmental benefits achieved through robust education and training programs aimed at improving energy code compliance. The developed methodology offers a standardized and easily replicable framework for states to quantitatively assess the performance of building energy codes and identify opportunities for improved compliance.

Acknowledgments

DOE would like to thank the eight project teams who participated in the pilot study:

- Alabama, Institute for Market Transformation (IMT)
- Arkansas, Southeast Energy Efficiency Alliance (SEEA)
- Georgia, SEEA
- Kentucky, Midwest Energy Efficiency Alliance (MEEA)
- Maryland, Maryland Energy Administration (MEA)
- North Carolina, Appalachian Energy Center (Center)
- Pennsylvania, Performance Systems Development (PSD)
- Texas, National Association of State Energy Officials (NASEO)

IMT is a Washington, DC-based nonprofit founded in 1996. IMT promotes energy efficiency, green building, and environmental protection in the United States and abroad. The prevailing focus of IMT's work is energy efficiency in buildings. Specific activities include technical and market research, policy and program development, and promotion of best practices and knowledge exchange. In particular, IMT aims to strengthen market recognition of the link between buildings' energy efficiency and their financial value. More information on IMT is available at http://www.imt.org/.

SEEA is a nonprofit founded in 2007 and is one of six regional energy efficiency organizations dedicated to leveraging energy efficiency for the benefit of all citizens. SEEA supports smarter energy policies, stronger local energy codes, resources to upgrade the existing building stock, and opportunities to provide equal access to affordable energy for all communities. SEEA works collaboratively with many different stakeholder groups to service utilities, businesses, and communities in 11 southeastern states, including Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. More information is available at http://seealliance.org/.

MEEA The Midwest Energy Efficiency Alliance (MEEA) is a collaborative network, promoting energy efficiency to optimize energy generation and consumption, create jobs and reduce carbon emissions for all Midwest communities. Learn more at http://www.mwalliance.org/.

MEA's mission is to promote affordable, secure, and safe energy while maintaining energy independence, sustainability, and reliability through innovative and effective policies, programs, technologies, and financing mechanisms. MEA advises the Governor on directions, policies, and changes in the various segments of the energy market. More information on MEA is available at http://energy.maryland.gov/Pages/default.aspx.

The **Center** is housed within the Research Institute for the Environment, Energy, and Economy at Appalachian State University. The mission of the Center is to conduct applied research and to provide services and education in support of the development and deployment of clean energy technologies, policies, and economies. One of the Center's initiatives is the North Carolina Energy Efficiency Alliance (NCEEA), which was established in 2010 as a state-funded non-profit organization with the goal of

supporting energy efficient and third party certified construction in NC. The NCEEA is dedicated to educating all the various stakeholders in the home building industry about the benefits of constructing energy efficient homes and buildings. More information is available at https://energy.appstate.edu and http://ncenergystar.org.

PSD is a technology-enabled energy efficiency program implementation firm with offices throughout the Northeast and Mid-Atlantic, and clients across the country. PSD's team of building scientists, energy engineers, program and project managers, and software developers work with a wide range of clients to design, deliver, and support utility-funded residential new construction programs, energy code training and code compliance enhancement programs, and operate third party Quality Assurance (QA) programs for residential, multifamily, and commercial programs. PSD is a Residential Energy Services Network-(RESNET)-accredited training provider, Building Performance Institute (BPI) training affiliate, and Home Energy Rating System (HERS) provider. PSD's industry-leading program management software platform, Compass, is utilized to track, manage, and report on energy savings activities in over 30 programs across the country. More information on PSD is available at http://www.psdconsulting.com.

NASEO is a national non-profit association for the governor-designated energy officials from each of the 56 states and territories. Formed by the states in 1986, NASEO facilitates peer learning among state energy officials, serves as a resource for and about state energy offices, and advocates the interests of the state energy offices to Congress and federal agencies. For more information on NASEO, visit http://www.naseo.org.

Acronyms and Abbreviations

AC	air conditioning
ACCA	Air Conditioning Contractors of America
ACH50	air changes per hour at 50 Pascals
AFUE	annual fuel utilization efficiency
AHU	air handling unit
BECP	Building Energy Codes Program
BPI	Building Performance Institute
Btu	British thermal unit
Center	Appalachian Energy Center
cfm	cubic feet per minute
CO2e	carbon dioxide equivalent
CZ	climate zone
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EUI	energy use intensity
FOA	funding opportunity announcement
HERS	Home Energy Rating System
HSPF	heating season performance factor
HVAC	heating, ventilation, and air conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IIQ	insulation installation quality
IMC	International Mechanical Code
IRC	International Residential Code
kBtu	thousand British thermal units
MEA	Maryland Energy Administration
MEEA	Midwest Energy Efficiency Alliance
MMBtu	million British thermal units
MT	metric ton
NA	not applicable
NASEO	National Association of State Energy Officials
NCEEA	North Carolina Energy Efficiency Alliance
PNNL	Pacific Northwest National Laboratory
PSD	Performance Systems Development
QA	quality assurance

RESNET	Residential Energy Services Network
SEEA	Southeast Energy Efficiency Alliance
SHGC	solar heat gain coefficient

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1.0 Introduction

A three-phase research project funded by the U.S. Department of Energy's (DOE's) Building Energy Codes Program (BECP) investigated opportunities to improve the energy efficiency and reduce homeowner utility bills across eight states through improved code compliance.[1] The study followed a prescribed methodology, which was followed by project teams in each state to build an empirical data set based on observations made directly in the field, which could then be analyzed to identify compliance trends, identify their impact on statewide energy consumption, and calculate savings that could be achieved through increased code compliance. These study findings can help states, utilities, and other industry stakeholders increase their return on investment through compliance-improvement initiatives, and the findings are intended to catalyze additional investments in workforce education, training, and related energy efficiency programs (DOE 2020).

Energy codes for residential buildings have advanced significantly in recent years, with today's model codes approximately 30% more efficient than codes adopted by the majority of U.S. states.[2] Hence, it is critical to ensure code-intended energy savings occur, so that homeowners realize the benefits of improved codes—something which happens only through high levels of compliance.

The data collected and analyzed for this report were in response to the DOE's Funding Opportunity Announcement (FOA),[3] with the goal of determining whether an investment in education, training, and outreach programs can produce a significant, measurable change in single-family residential building code energy use. Participating states did the following:

I. Conducted a baseline field study to determine installed energy values of code-required items, identified issues, and calculated savings opportunities [Phase I];

II. Implemented education and training activities designed to increase code compliance [Phase II]; and

III. Conducted a second field study to re-measure the post-training values using the same methodology as the baseline study [Phase III].

When the studies began, most states were on some version of the 2009 International Energy Conservation Code (IECC) with one state on the 2015 IECC. By the time the studies concluded, more states had gone to a version of the 2015 IECC. This is represented in Figure 1.1, which provides a breakdown of the energy code used per building visited during Phase I and Phase III data collection.

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[1] Seven of the eight states completed all phases of the study, where Arkansas only completed Phase I due to limited potential savings. This report focuses on the seven states for consistent comparisons across phases and states. The full Phase I Arkansas Report is available at https://www.energycodes.gov/sites/default/files/documents/Arkansas_Residential_Field_Study.pdf

[2] Available at https://www.energycodes.gov/adoption/state-code-adoption-tracking-analysis

[3] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study

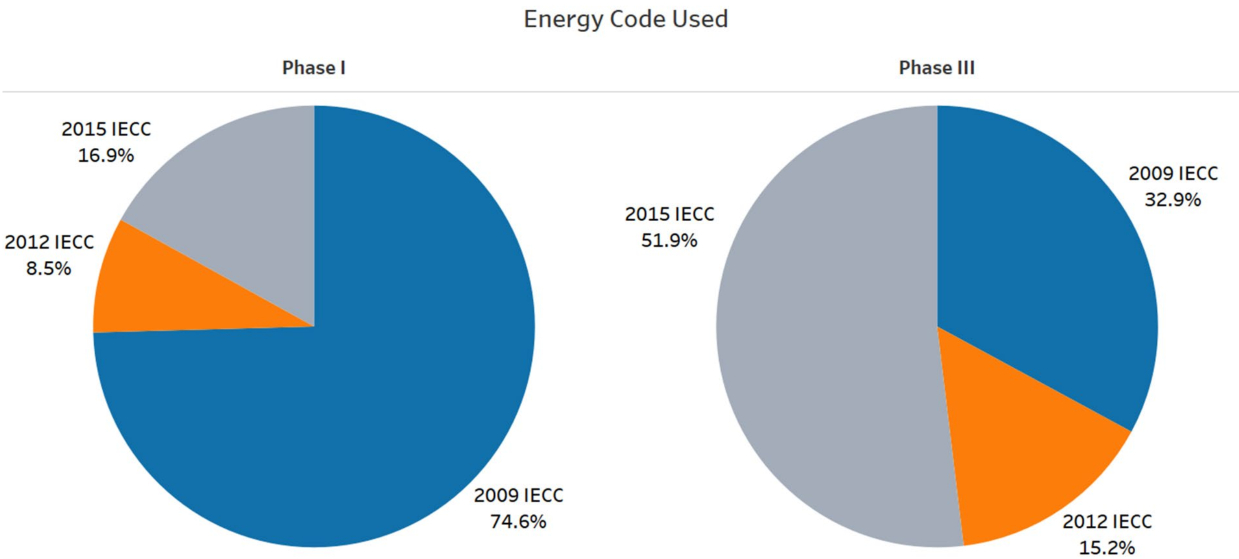

Figure 1.1. Phase I & Phase III Referenced Energy Code Version[4]

Methodology

Project teams applied a methodology prescribed by DOE (DOE 2018),[5] which was based on collecting information for the energy code-required building components with the largest direct impact on energy consumption. These *key items* were a focal point of the study and drove the analysis and savings estimates. The project teams implemented customized state-specific sampling plans representative of new construction within each state, which were initially developed by Pacific Northwest National Laboratory (PNNL), and then vetted through public meetings with key state stakeholders.

Following each data collection phase, PNNL conducted three stages of analysis on the resulting data set (Figure 1.2). The first stage identified compliance trends within the state based on the distributions observed in the field for each key item. The second modeled energy consumption of the homes observed in the field relative to what would be expected if sampled homes just met minimum code requirements. The third stage then calculated results based on three metrics emphasized by states as of interest relative to tracking code implementation status—potential energy savings, consumer cost savings, and environmental impacts associated with increased code compliance. Together, these findings provide valuable insight on challenges facing energy code implementation and enforcement.

[4] This represents the energy code selected by the builder during Phase I and Phase III data collection. As described in the report, many of these codes include statewide amendments.
[5] A working methodology was developed in partnership with the FOA recipients in 2014, which was used for Phase I data collection.

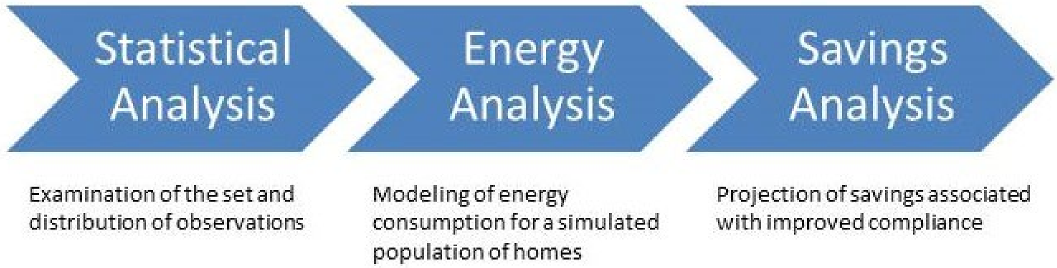

Figure 1.2. Stages of Analysis Applied in the Study

Highlights of the methodology are as follows:

- Focuses on **individual code requirements** within **new single-family homes**
- Based on a **single site visit** to reduce the burden and minimize bias
- Prioritizes **key items** with the greatest impact on energy consumption
- Designed to produce **statistically significant results**
- **Has data confidentiality** built into the experiment—no occupied homes were visited, and no personal data shared
- Produces results based on an **energy metric** and reported at the **state level.**[6]

PNNL identified the code-requirements (and associated energy efficiency measures) with the greatest direct impact on residential energy consumption.[7] These key items drive sampling, data analysis, and eventual savings projections:

1. Envelope tightness (air changes per hour at 50 Pascals [ACH50])
2. Windows (U-factor and solar heat gain coefficient [SHGC])
3. Wall insulation (R-value and assembly U-factor)
4. Ceiling insulation (R-value and assembly U-factor)
5. Lighting (% high-efficacy)
6. Foundation insulation (R-value and assembly U-factor)[8]
7. Duct tightness (cubic feet per minute [cfm] per 100 ft^2 of conditioned floor area at 25 Pascals).

PNNL evaluated the variability associated with each key item and concluded that a minimum of 63 observations would be needed for each one to produce statistically significant results at the state level. Both the key items themselves and the required number of observations were prescribed in the DOE

[6] Savings for all states are reported at the statewide level except for Texas which is reported at the CZ 2A level in this report. Data was collected in 30 counties in and around Houston so the project team requested the analytical results to be calculated for CZ 2A only and at the statewide level. Statewide numbers can be found in Appendix E of the Texas Residential Energy Code Field Study: Final Report, available at https://www.energycodes.gov/compliance/energy-code-field-studies.
[7] This is based on the mandatory and prescriptive requirements of the IECC.
[8] Floor insulation, basement wall insulation, crawlspace wall insulation, and slab insulation are combined into a single category of foundation insulation. A comparison of types and insulation levels is found in Appendix A.

methodology.

A separate document describes the methodology in detail (DOE 2018). More information on the FOA and overall DOE interest in compliance is available on the DOE Building Energy Codes Program website.[9]

[9] Available at https://www.energycodes.gov/compliance

2.0 Summary of Phase I Results

A summary of Phase I results is provided for the seven states that participated in the full scope of the original FOA. A Phase I report was published for each state,[10] including three sets of results: distributions of key item observations, comparison of average expected and observed EUIs, and measure level savings potential. Table 2.1 provides the expected EUI based on the energy use of a home complying with the state prescriptive compliance pathway and mean observed EUI for each state. In the difference column, a negative number indicates less energy use in the observed Phase I EUI than the expected (code baseline) EUI, where a positive number means more energy use on average. Table 2.2 shows the Phase I compliance rate of all measure observations for each state.

Table 2.1. Phase I Average Modeled Energy Use Intensity (kBtu/ft^2-yr)

State	State Code Analyzed	Expected EUI (kBtu/ft^2)	Observed EUI (kBtu/ft^2)	Difference (%)
PA	2009 IECC (2009 IRC)	45.48	40.73	-10.4%
MD	2015 IECC	27.56	30.49	10.6%
KY	2009 IECC	33.98	31.31	-7.9%
NC	2012 NC Energy Code (amended 2009 IECC)	23.79	22.96	-3.5%
GA	Georgia Energy Code (amended 2009 IECC)	28.52	26.52	-7.0%
AL	2015 AL Code (amended 2015 IECC)	18.41	19.81	7.6%
TX (CZ2a)	2015 IECC	22.15	22.57	1.9%

Table 2.2. Phase I Average Measure Level Compliance Rate (%)

State	Envelope Tightness	Duct Tightness	Wall Insulation U-factor	Ceiling Insulation U-factor	Lighting	Window U-factor	Window SHGC
PA	93%	63%	23%	49%	62%	97%	-
MD	54%	62%	25%	69%	61%	98%	-
KY	70%	77%	28%	41%	31%	98%	-
NC	88%	64%	12%	64%	57%	99%	99%
GA	96%	69%	17%	11%	38%	100%	98%
AL	46%	15%	16%	75%	21%	94%	74%
TX (CZ2a)	60%	19%	65%	59%	48%	94%	94%

Results were generally favorable on average on a statewide EUI basis, in fact, much better than anticipated. Homes are using less energy on average than expected based on prescriptive measures for most states. Surprisingly, certain measures, such as windows, almost universally met code. Others, such as lighting and wall insulation U-factor, were worse than expected. Overall, trends vary by measure and

[10] All Phase I reports are available at https://www.energycodes.gov/compliance/energy-code-field-studies.

state, and insulation installation quality (IIQ) matters, but there are still significant savings left on the table.

2.1 Phase I Field Observations

The field study methodology called for at least 63 observations of the eight key items per state identified in Section 1.0 of this report. Although each field team collected the necessary amount of data, only certain measures demonstrated significant levels of non-compliance, or unexpected findings, which are captured in this report. The following subsections provide a cross-state comparison of these measures to identify trends and takeaways from the key measure data collected in Phase I. Figure 2.1 shows an example for frame wall insulation.

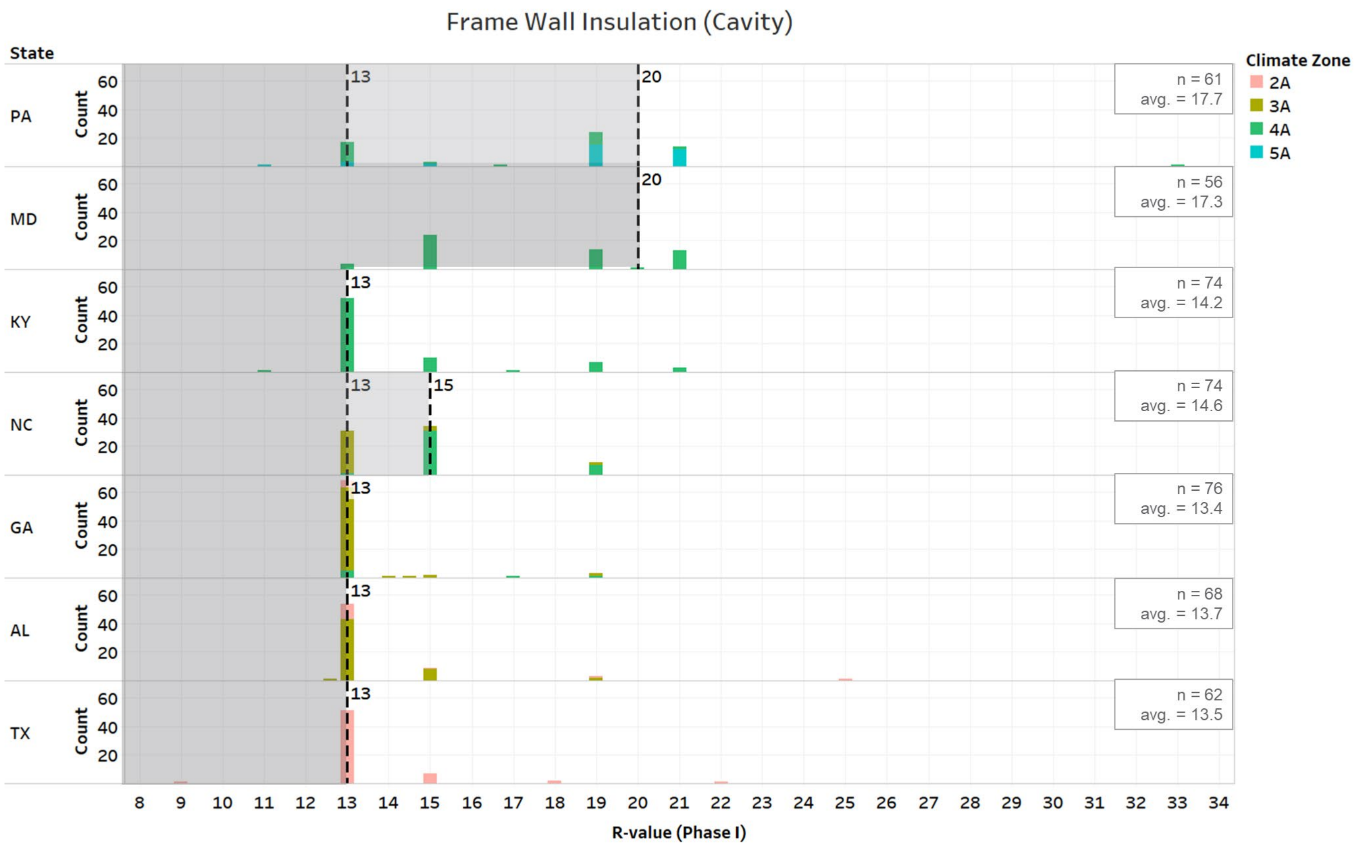

Figure 2.1. Measure Level Cross-State Comparison Example

Each graph is set up similar to the example in Figure 2.1, identifying the *states*, *climate zones*, and the specific item analyzed. States are presented in order of highest climate zone to lowest climate zone, which is identified by the colors in the climate zone key in the upper right-hand corner. The total *sample size* (n) for each state is displayed in the top right corner of the graph, along with the distribution *average*. The *metric* associated with the item is measured along the horizontal axis (e.g., wall cavity R-value), and a *percentage* of the number of observations per state is measured along the vertical axis. The vertical lines imposed on the graph represent the applicable code requirements in each state. If a state has multiple prescriptive requirements due to multiple climate zones, multiple vertical lines are present (e.g., in Pennsylvania, the prescriptive requirement in CZ4 is R-13 and CZ5 is R-20). Values to the right-hand side of each line represent observations that are *better than code*. Values to the left-hand side and greyed out represent areas for improvement.

2.1.1 Envelope Tightness

Figure 2.2 shows a comparison of Phase I envelope tightness by state.

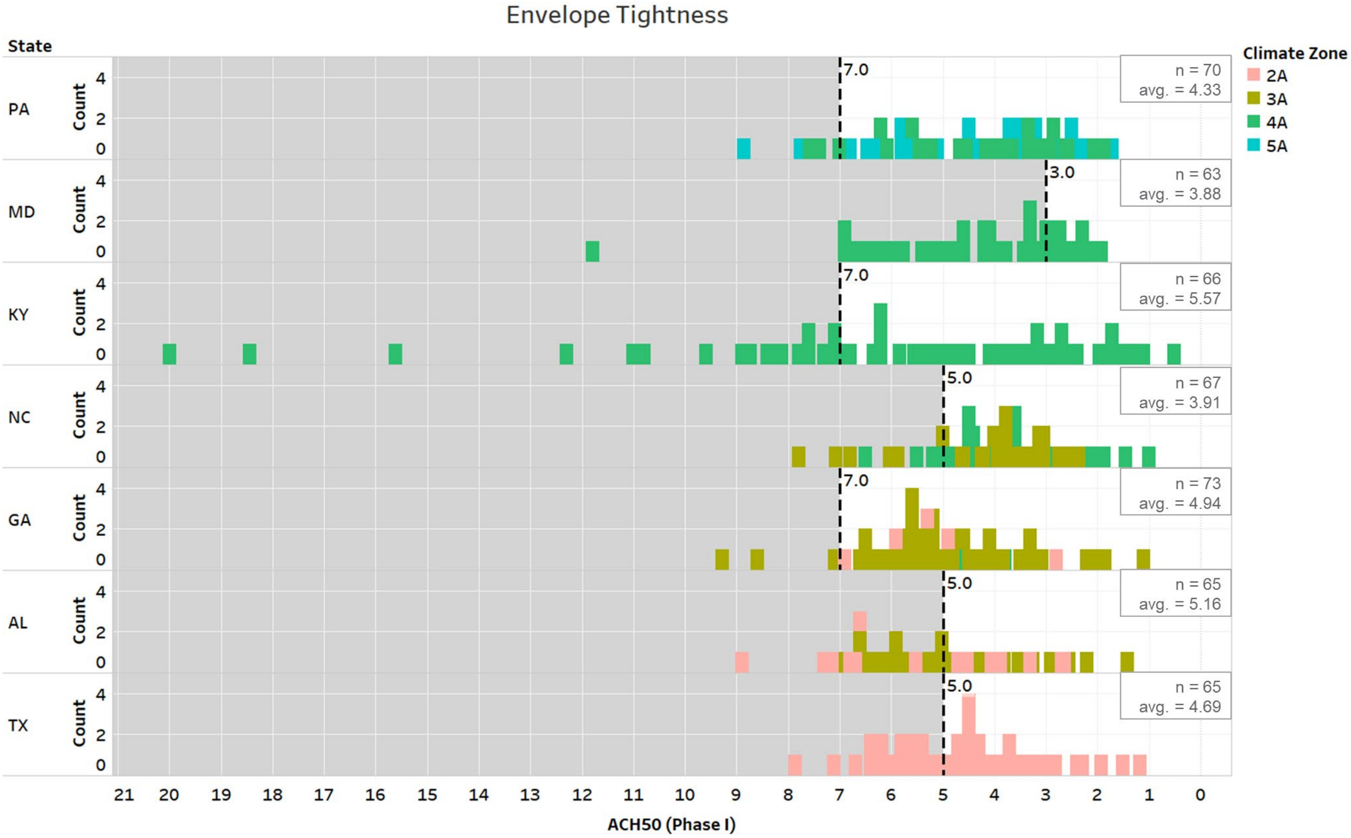

Figure 2.2. Comparison of Phase I Envelope Tightness by State

As shown in Figure 2.2 and Table 2.3, compliance with envelope tightness is mixed, with almost half of the states (PA, NC, GA) with high rates of compliance and the remaining states with ~50–70% compliance. States with high compliance rates tend to have a higher (less stringent) envelope tightness threshold as found in the 2009 IECC and typically do not require blower door testing. States with a recently updated energy code and a more stringent leakage rate (MD, TX) demonstrated relatively low compliance and significant energy savings potential.

Table 2.3 Phase I Envelope Tightness Compliance Rate

State	Code Requirement	Phase I (Compliance Rate)
Pennsylvania	7 ACH50	65 of 70 (93%)
Maryland	3 ACH50	34 of 63 (54%)
Kentucky	7 ACH50	46 of 66 (70%)

North Carolina	5 ACH50	59 of 67 (88%)
Georgia	7 ACH50	70 of 73 (96%)
Alabama	5 ACH50	30 of 65 (46%)
Texas	5 ACH50	39 of 65 (60%)

2.1.2 Duct Tightness

Duct tightness is reported as both unadjusted (raw) and adjusted, as shown in Figure 2.3 and Figure 2.4. Unadjusted is simply the values of duct tightness observed in the field. Adjusted duct tightness looks at the location of the ducts and adjusts the values for any ducts that are entirely in conditioned space by setting those values to 0. The adjustment reflects the fact that duct tightness tests are not required if the ducts are entirely in conditioned space.

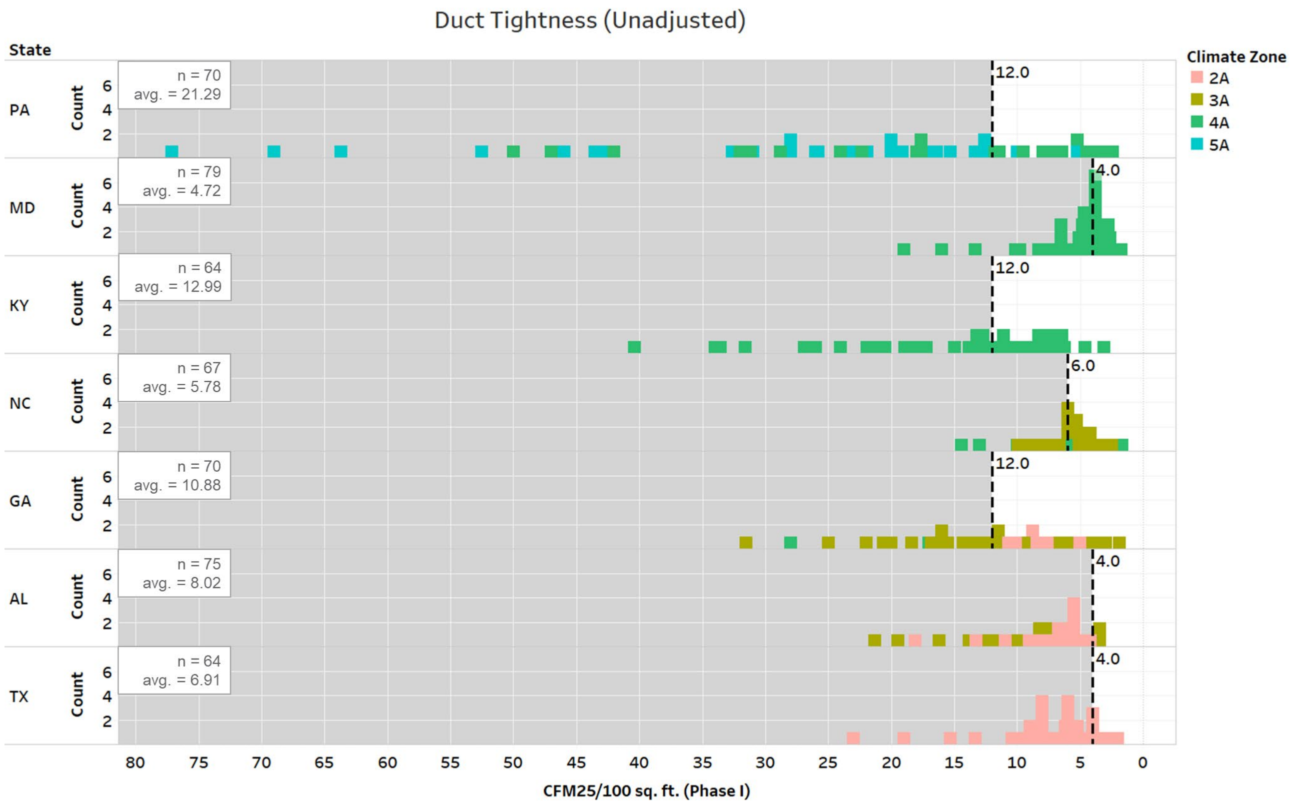

Figure 2.3. Comparison of Phase I Duct Tightness (Unadjusted) by State

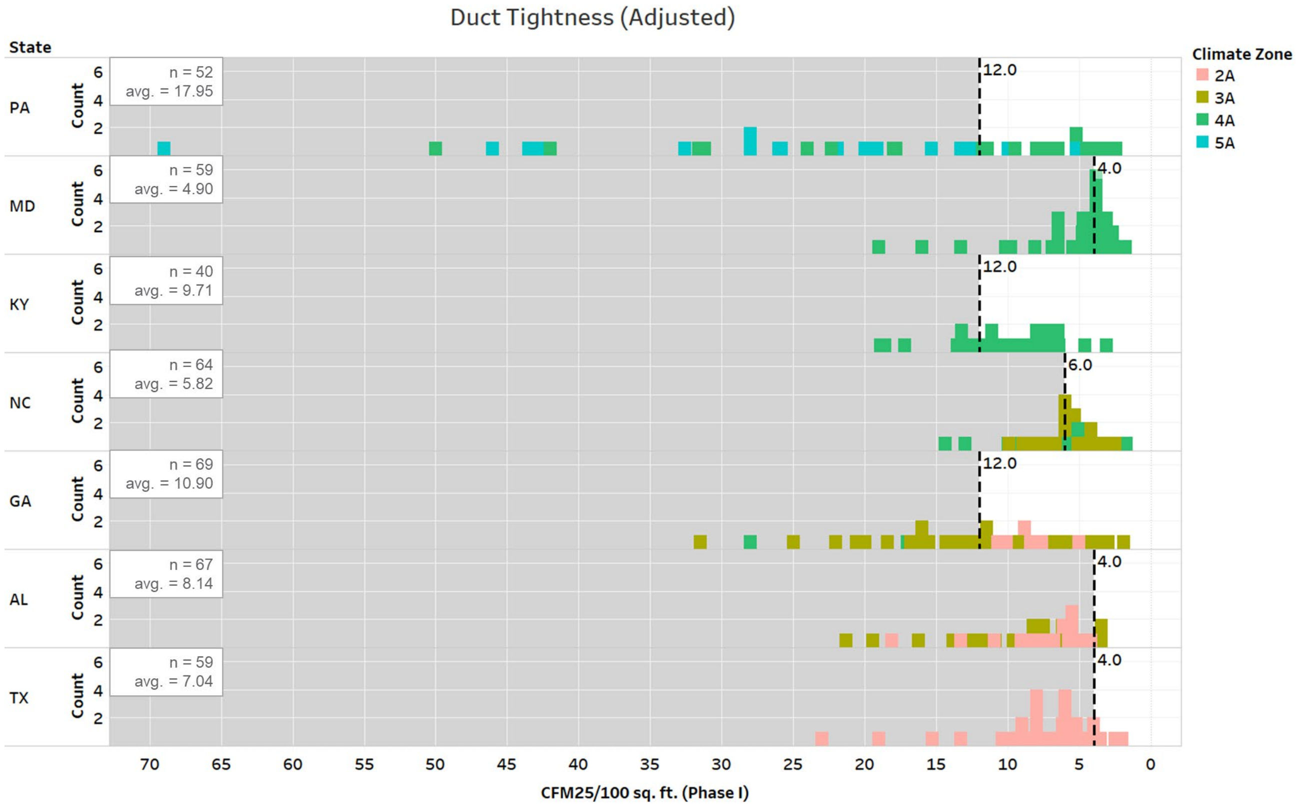

Figure 2.4. Comparison of Phase I Duct Tightness (Adjusted) by State[11]

Table 2.4 shows the Phase I duct tightness compliance rates for the states. Similar duct leakage trends are observed across each state, with some states exhibiting a greater prevalence of leakier ducts than others. Since field teams conducted duct tightness testing in all states, observations for this item include homes where ducts were located entirely in conditioned space. At least one state exhibited a trend of having its leakiest ducts within conditioned space.

Table 2.4. Phase I Duct Tightness Compliance Rate (Adjusted)

State	Code Requirement (cfm25/100 ft^2)	Phase I (Compliance Rate)
Pennsylvania	12.0	44 of 70 (63%)
Maryland	4.0	49 of 79 (62%)
Kentucky	12.0	31 of 40 (77%)
--North Carolina	6.0	43 of 67 (64%)
Georgia	12.0	48 of 70 (69%)
Alabama	4.0	11 of 75 (15%)
Texas	4.0	12 of 64 (19%)

[11] Although in the analysis we set adjusted values of ducts entirely in conditioned space to 0, to better demonstrate data trends, we have excluded the observations that were set to 0 from this graph. A total of 79 observations across all states were set to 0 and excluded from this graph.

2.1.3 Wall Insulation

Wall insulation data are presented in terms of both frame cavity insulation and overall assembly performance in order to capture the conditions seen in the field. The cavity insulation data are based on the observed value (R-value), as printed on the manufacturer label and installed in the home, and shown in Figure 2.5. While cavity insulation is important, it is not fully representative of wall assembly performance, since this data point alone does not account for other factors that can have a significant effect on the wall system such as combinations of cavity and continuous insulation and IIQ. (See Figure 2.6 for an IIQ comparison.) Therefore, wall insulation is also presented from a second perspective—overall assembly performance (U-factor), as shown in Figure 2.7.

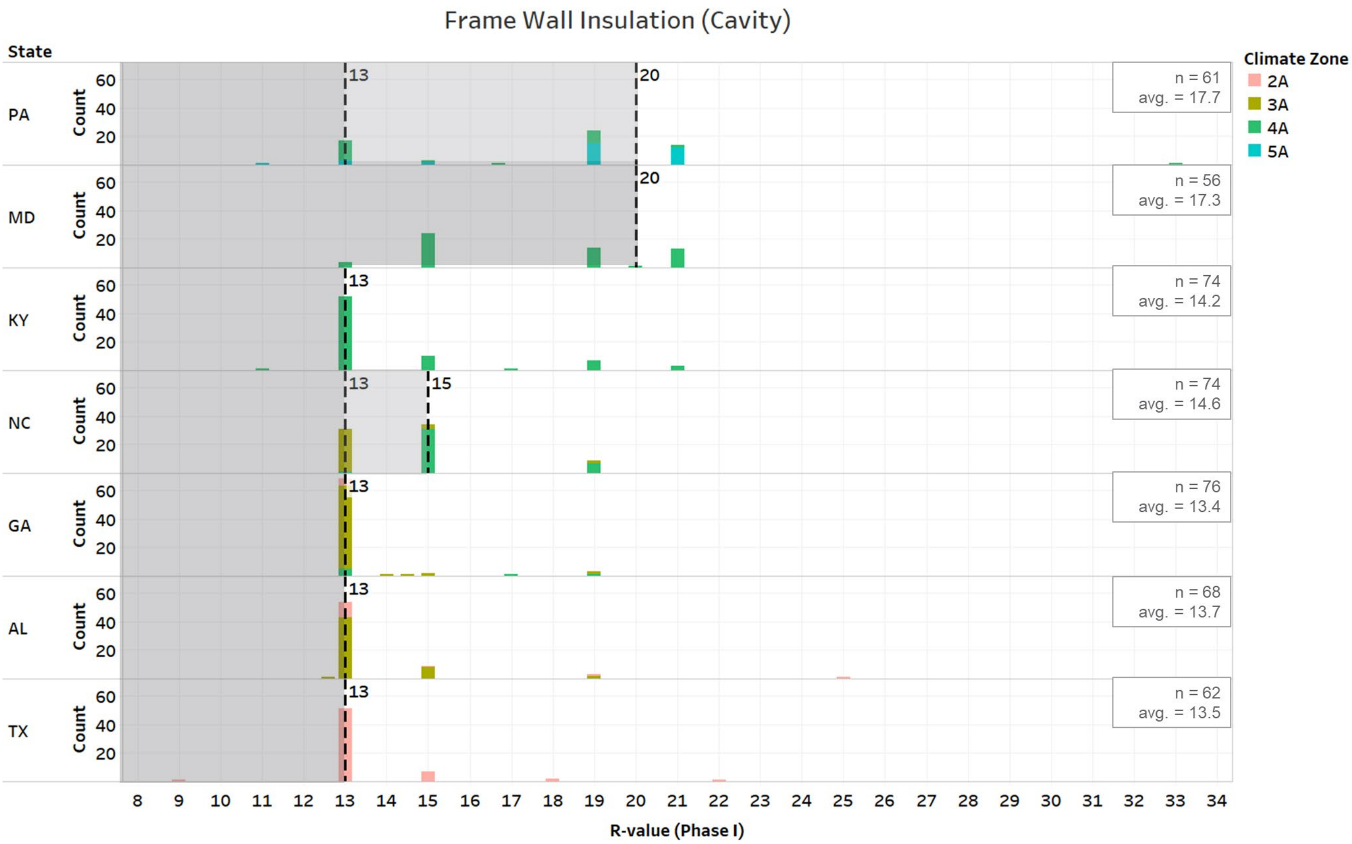

Figure 2.5. Comparison of Phase I Frame Wall Cavity Insulation (R-value)

Insulation Installation Quality (IIQ)

At the start of the overall project, IIQ was noted as a particular concern among project teams and stakeholders, as it plays an important role in the energy performance of envelope assemblies. IIQ was therefore collected by the field teams whenever possible (see Figure 2.6), and applied as a modifier in the analyses for applicable key items (i.e., ceiling insulation, wall insulation, and foundation insulation). Teams followed the Residential Energy Services Network (RESNET)[12] assessment protocol for cavity

[12] Based on the RESNET definition and classification of IIQ in Chapter 8 of http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf.

insulation, which has three grades with Grade I indicating the best quality installation and Grade III indicating the worst.

Wall Cavity Insulation (IIQ)	PA	MD	KY	NC	GA	AL	TX
I	32%	59%	35%	45%	14%	12%	61%
II	65%	38%	52%	55%	37%	77%	31%
III	3%	4%	13%		49%	11%	8%

Figure 2.6. Comparison of Phase I Frame Wall Cavity Insulation Installation Quality (IIQ)

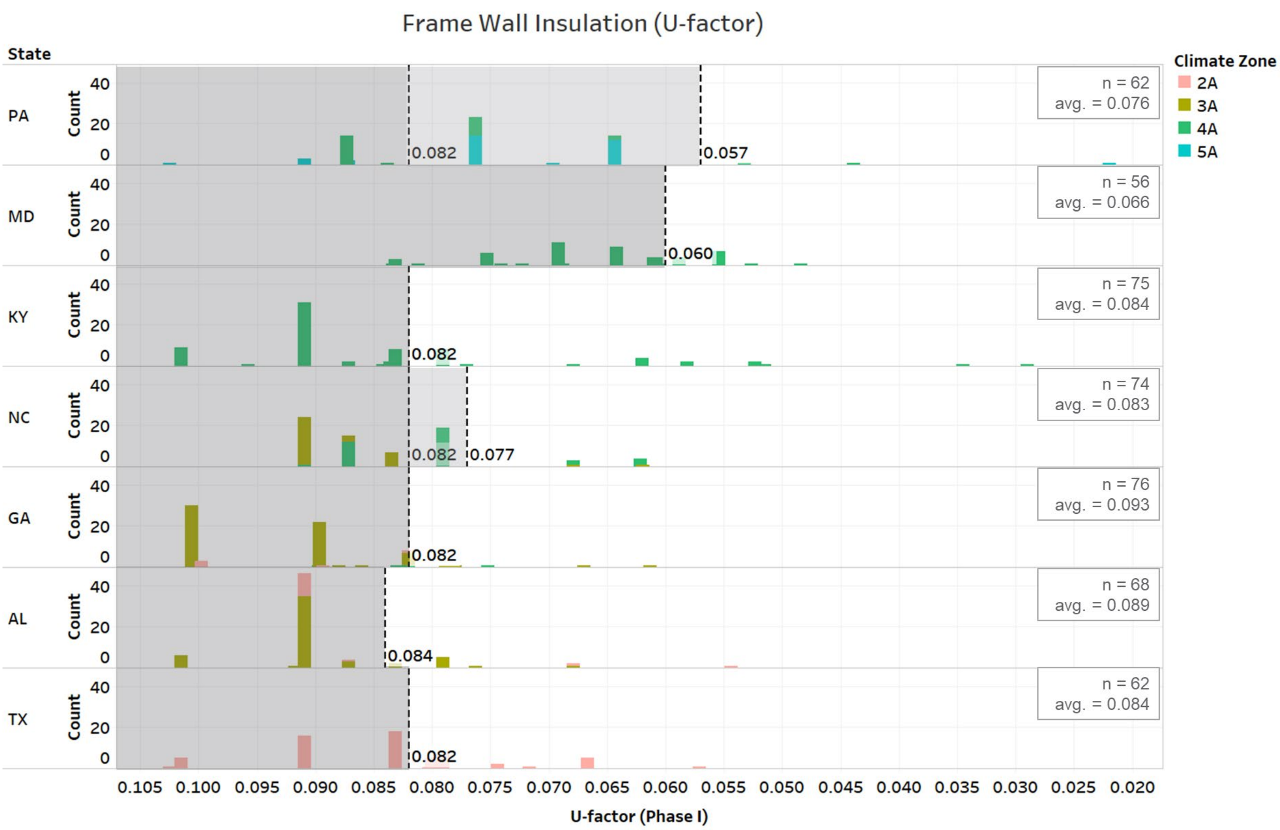

Figure 2.7. Comparison of Phase I Frame Wall Insulation (U-factor)

To capture the presence of both cavity and continuous insulation, as well as to include the effect of IIQ, wall assembly U-factors were calculated as shown in Table 2.5. A key finding is that while most homes exhibited the correct insulation R-value, IIQ was typically observed as Grade II or Grade III, which in turn degraded the overall wall assembly U-factor. While not an explicit requirement in the IECC, IIQ was found to have a considerable effect on overall wall performance.

Table 2.5. Phase I Frame Wall Insulation Compliance Rate (U-factor)

State	Code Requirement (U-factor)	Phase I (Compliance Rate)
Pennsylvania	0.082 (CZ4); 0.057 (CZ5)	14 of 62 (23%)
Maryland	0.060	14 of 56 (25%)
Kentucky	0.082	21 of 75 (28%)
North Carolina	0.082 (CZ3); 0.077 (CZ4); 0.060 (CZ5)	9 of 74 (12%)
Georgia	0.082	13 of 76 (17%)
Alabama	0.084	11 of 68 (16%)
Texas	0.082	40 of 62 (65%)

2.1.4 Ceiling Insulation

Ceiling insulation data are presented in terms of both frame cavity insulation and overall assembly performance in order to capture the conditions seen in the field. The cavity insulation data are based on the observed, measured R-value, as installed in the home, and shown in Figure 2.8 and Table 2.6. While cavity insulation is important, it is not fully representative of ceiling assembly performance, since this data point alone does not account for other factors that can have a significant effect on the assembly, such as combinations of cavity insulation and IIQ, as shown in. Figure 2.9. Therefore, ceiling insulation is also presented from a second perspective—overall assembly performance (U-factor), as shown in Figure 2.10 and Table 2.7.

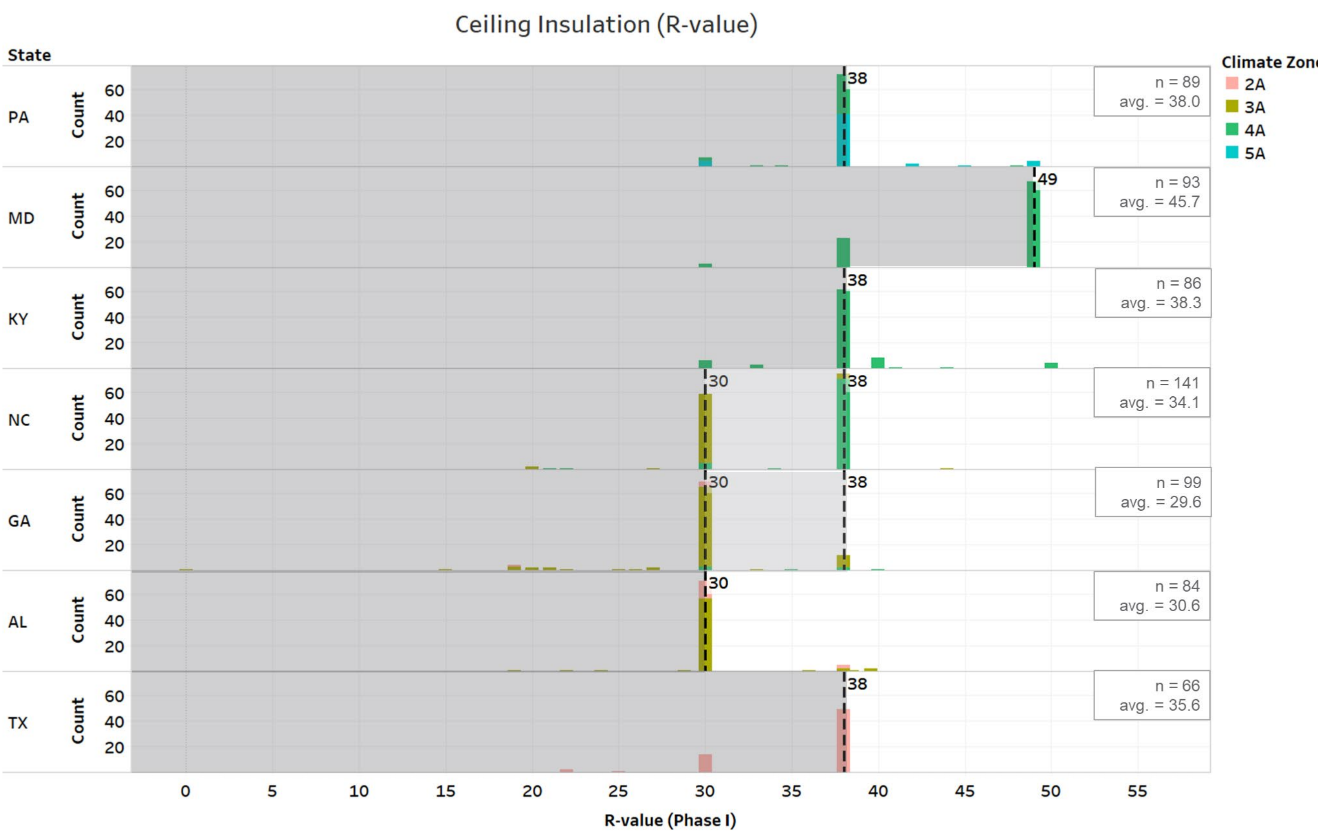

Figure 2.8. Comparison of Phase I Ceiling Insulation (R-value)

Table 2.6. Phase I Ceiling Insulation Compliance Rate (R-value)

State	Code Requirement (R-value)	Phase I (Compliance Rate)
Pennsylvania	38	80 of 89 (90%)
Maryland	49	67 or 93 (72%)
Kentucky	38	77 of 86 (90%)
North Carolina	30 (CZ3); 38 (CZ4&5)	130 of 141 (92%)
Georgia	30 (CZ2&3); 38 (CZ4)	83 of 99 (83%)
Alabama	30	80 of 84 (95%)
Texas	38	49 of 66 (74%)

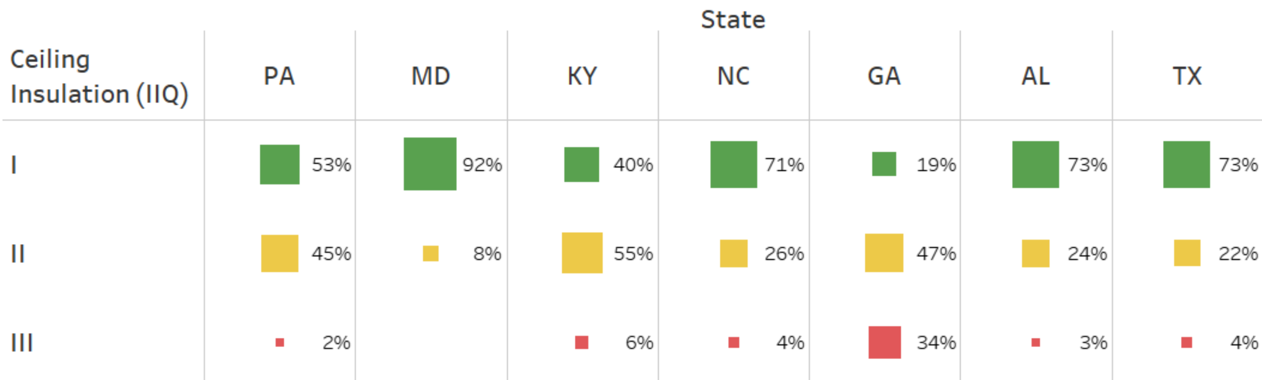

Figure 2.9. Comparison of Phase I Ceiling Insulation Installation Quality (IIQ)

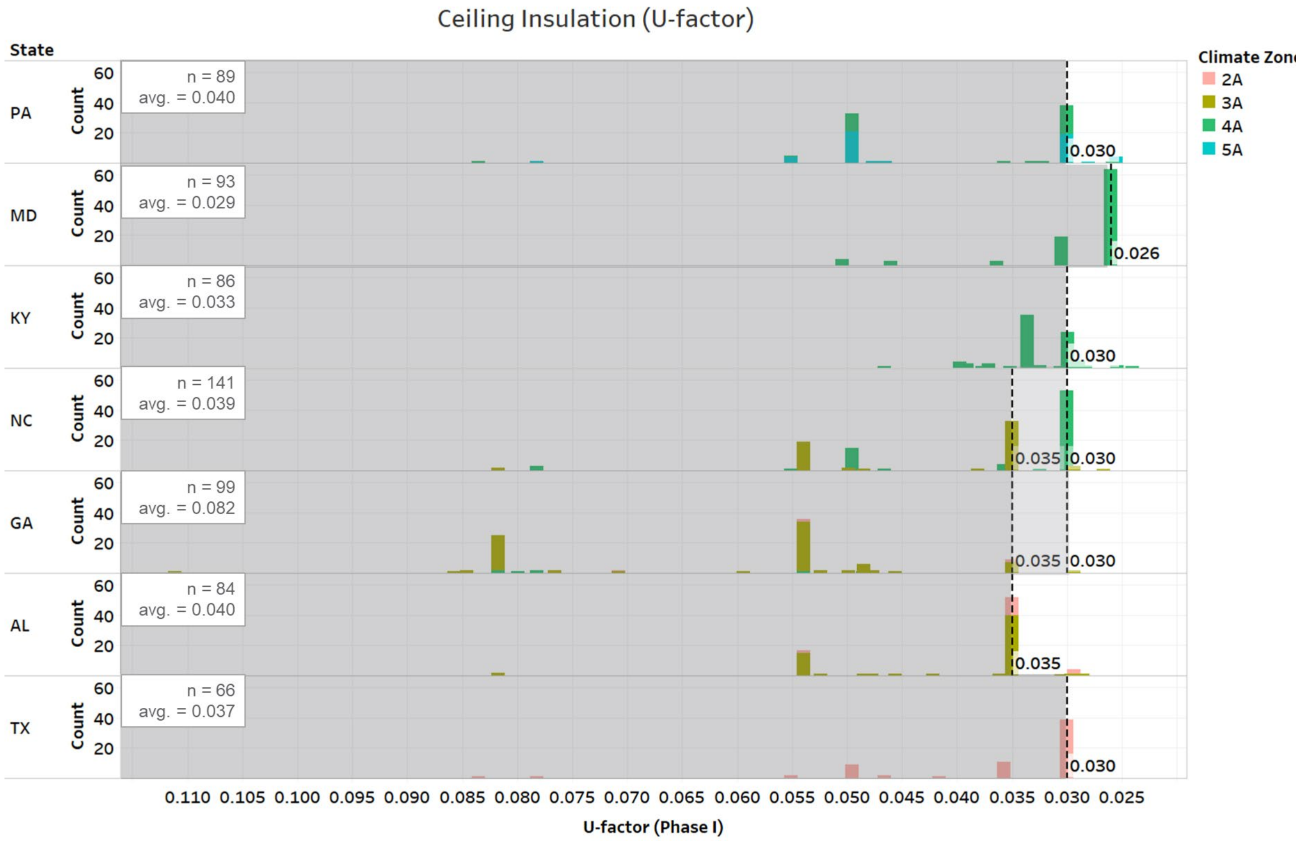

Figure 2.10. Comparison of Phase I Ceiling Insulation (U-factor)

Table 2.7. Phase I Ceiling Insulation Compliance Rate (U-factor)

State	Code Requirement (U-factor)	Phase I (Compliance Rate)
Pennsylvania	0.030	44 of 89 (49%)
Maryland	0.026	64 of 93 (69%)
Kentucky	0.030	35 of 86 (41%)
North Carolina	0.035 (CZ3); 0.030 (CZ4&5)	90 of 141 (64%)
Georgia	0.035 (CZ2&3); 0.030 (CZ4)	11 of 99 (11%)
Alabama	0.035	63 of 84 (75%)
Texas	0.030	39 of 66 (59%)

Similar to frame wall cavity observations, ceiling insulation displayed a relatively high level of compliance when only assessing the level of insulation installed. However, when factoring in the impact of IIQ, the level of compliance decreases significantly. As observed in Figure 2.8 and Figure 2.10, the compliance rate decreases from 72–95% when only considering insulation R-value to 11-75% when considering the impact of IIQ on the ceiling assembly, depending on the state.

2.1.5 High-Efficacy Lighting

The results for high-efficacy lighting are shown in Figure 2.11 and Table 2.8.

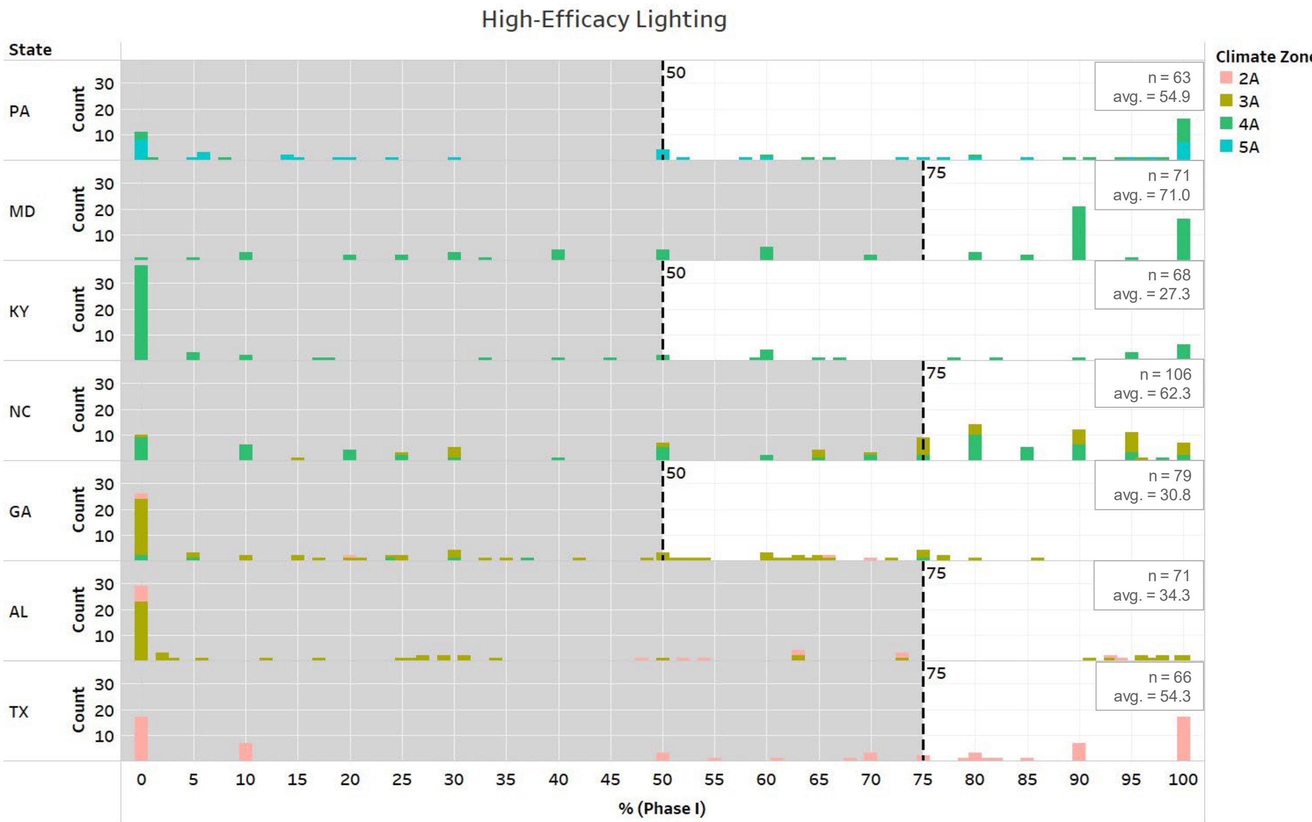

Figure 2.11 Comparison of Phase I High-Efficacy Lighting (%)

Table 2.8. Phase I High-Efficacy Lighting Compliance Rate

State	Code Requirement	Phase I (Compliance Rate)
Pennsylvania	50%	39 of 63 (62%)
Maryland	75%	43 of 71 (61%)
Kentucky	50%	21 of 68 (31%)
North Carolina	75%	60 of 106 (57%)
Georgia	50%	29 of 79 (38%)
Alabama	75%	15 of 71 (21%)
Texas	75%	32 of 66 (48%)

High-efficacy lighting was another key area of non-compliance among the seven states in the study. Compliance rates ranged from a low of 21% in Alabama with over 41% of observations not installing any high-efficacy lighting, to a high of 62% in Pennsylvania.

2.1.6 Windows

Figure 2.12, Figure 2.13, Table 2.9, and Table 2.10 display the results for windows.

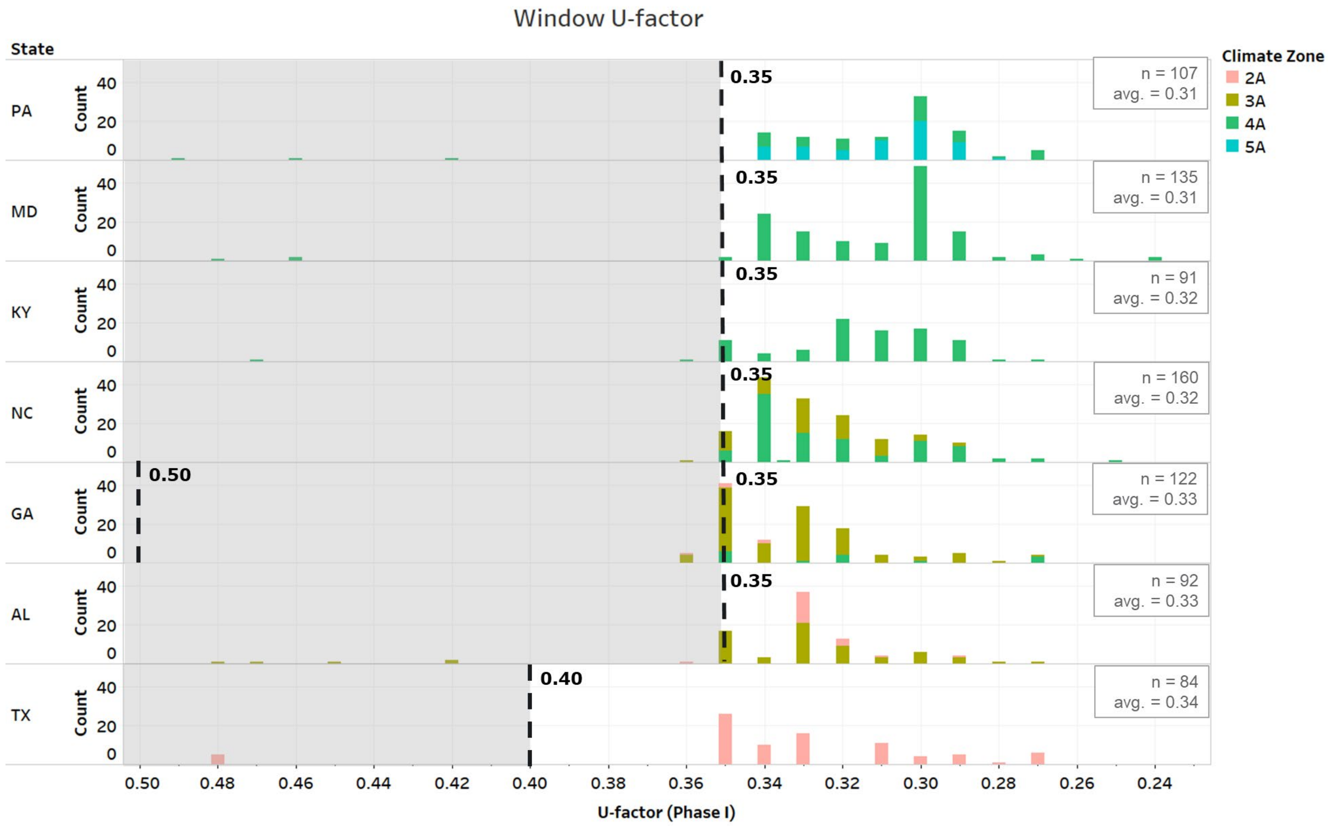

Figure 2.12 Comparison of Phase I Window U-factor

Table 2.9. Phase I Window U-factor Compliance Rate

State	Code Requirement (U-factor)	Phase I (Compliance Rate)
Pennsylvania	0.35	104 of 107 (97%)
Maryland	0.35	132 of 135 (98%)
Kentucky	0.35	89 of 91 (98%)
North Carolina	0.35	159 of 160 (99%)
Georgia	0.5 (CZ2&3); 0.35 (CZ4)	122 of 122 (100%)
Alabama	0.35	86 of 92 (94%)
Texas	0.40	79 of 84 (94%)

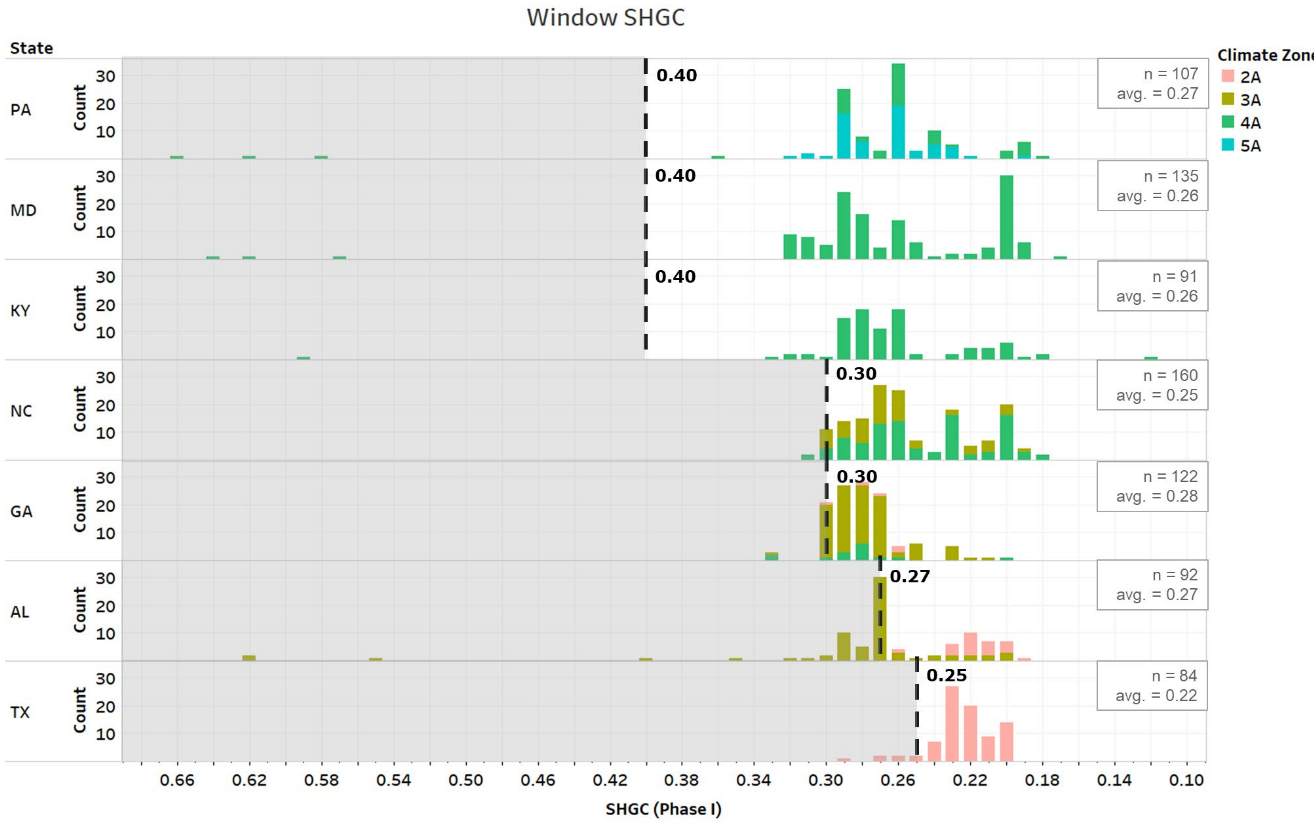

Figure 2.13 Comparison of Phase I Window SHGC

Table 2.10. Phase I Window SHGC Compliance Rate

State	Code Requirement (SHGC)[(a)]	Phase I (Compliance Rate)
Pennsylvania	0.4	-
Maryland	0.4	-
Kentucky	0.4	-
North Carolina	0.3	158 of 160 (99%)
Georgia	0.3	119 of 122 (98%)
Alabama	0.27	68 of 92 (74%)
Texas	0.25	79 of 84 (94%)

(a) Note that the 0.4 SHGC value listed for Pennsylvania and Kentucky is the analysis default used by BECP for states or climate zones that do not have SHGC requirements. Pennsylvania and Kentucky use the 2009 IECC, and there is no SHGC requirement above Climate Zone 3. The 0.4 SHGC requirement in Maryland, which uses the 2015 IECC, is an actual SHGC requirement for Climate Zone 4.

The vast majority of window U-factor observations are at 0.35 or below, regardless of state, climate zone, or baseline code. There is some evidence that lower U-factors are used in colder climate zones, but even warm climate zones tend to have most of their observations at 0.35 or better. Window SHGC shows a similar distribution, with most observations collected at 0.30 or below.

2.2 Comparison of Expected and Observed Energy Consumption

The next stage of the analysis leveraged the statistical analysis results to model average statewide energy consumption. A consequence of the field study methodology allowing only one site visit per home to minimize bias is that a full set of data cannot be gathered on any single home, as not all energy-efficiency measures are in place or visible at any given point during the home construction process. This lack of complete data for individual homes creates an analytical challenge, because energy modeling and simulation protocols require a complete set of inputs to generate reliable results. To address this challenge, a series of "pseudo homes" were created, comprised of over 1,500 models encompassing most of the possible combinations of key item values found in the observed field data. In aggregate, the models provide a statistical representation of each state's population of newly constructed homes. This approach is known in statistics as a Monte Carlo analysis.

Energy simulation was then conducted using the EnergyPlus™ software. Each of the 1,500 models was run multiple times, to represent each combination of heating systems and foundation types commonly found in each state. This resulted in upwards of 30,000 simulation runs for each climate zone within each state.

Average EUI in each state was calculated based on regulated end uses (heating, cooling, lighting and domestic hot water) for two sets of homes—one as-built set based on the data collected in the field, and a second code-minimum set (i.e., exactly meeting minimum code requirements). Comparing these values shows whether the population of newly constructed homes in the state is using more or less energy than would be expected based on minimum code requirements. In the energy analysis, the presence of both above code and below code items is included and therefore reflected in the statewide EUI.[13]

Table 2.11 compares the average expected EUI based on the energy use of a home complying with the state prescriptive compliance pathway and average observed EUI for each state.[14]

Table 2.11. Phase I Average Statewide Energy Consumption

State	Current State Energy Code	Expected EUI ($kBtu/ft^2$)	Observed EUI ($kBtu/ft^2$)	Differential (%)
PA	2009 IECC (2009 IRC)	45.48	40.73	-10.4%
MD	2015 IECC	27.56	30.49	10.6%
KY	2009 IECC	33.98	31.31	-7.9%
NC	2012 NC Energy Code (amended 2009 IECC)	23.79	22.96	-3.5%
GA	Georgia Energy Code (amended 2009 IECC)	28.52	26.52	-7.0%
AL	2015 AL Code (amended 2015 IECC)[(a)]	18.41	19.81	7.6%

[13] Further specifics of the EUI energy analysis are available in a supplemental methodology report (DOE 2018).

[14] See individual state reports for a full accounting of baseline codes included in the state-level analysis, including the measure-level savings opportunities of bringing individual measures into compliance with prescriptive requirements.

State	Current State Energy Code	Expected EUI (kBtu/ft^2)	Observed EUI (kBtu/ft^2)	Differential (%)
TX	2015 IECC	22.15	22.57	1.9%

(a) At the time of the initiation of Phase I of the study, the state energy code was based on the 2009 IECC. Following data collection in Phase I, the state adopted an updated energy code, known as the 2015 Alabama Residential Energy Code. All of the results noted in this report are based on the 2015 Alabama code.

The differential between *observed* and *expected* EUIs ranged from a low of approximately negative 10% to a high of nearly positive 11%, with positive values indicating that the *observed* EUI was higher than the expected EUI (based on prescriptive code requirements). Table 2.11 suggests very high rates of state energy code compliance when compared to the 2009 IECC but relatively low compliance when compared to the 2015 IECC baseline. However, it is noted that this metric combines *all* field data points, including the offsetting effects of individual measures that are better or worse than the prescriptive code requirement, therefore masking the savings opportunities associated with individual measures. While the energy metric is most indicative of average statewide energy use, the measure-level savings metric (described in Section 2.3) is appropriate for determining the savings potential associated with individual energy efficiency measures.

Figure 2.14 compares the distribution of Phase I EUIs for all states to the expected (prescriptive) EUI represented with the vertical dash line. As with the measure level graphs in the previous section, anything to the left of the line uses more energy than a home built to prescriptive code measures, while anything to the right uses less energy. As visible in the graph, energy use is driven by both climate zone and code stringency.

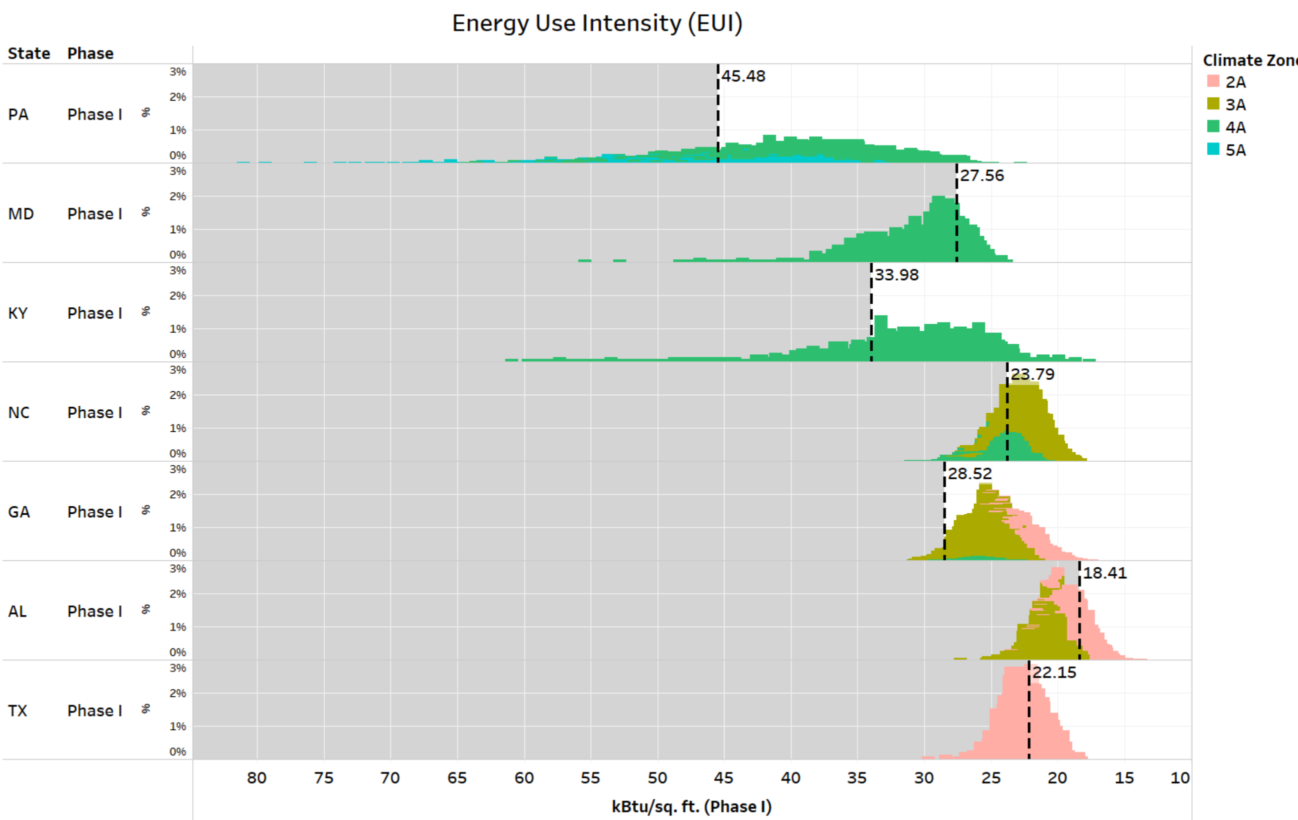

Figure 2.14 Comparison of Phase I Statewide EUIs

2.3 Measure Savings

One objective of the baseline pilot studies was to identify measures on which to focus continued energy code education, training, and outreach activities in Phase II. PNNL calculated energy savings, energy cost savings, and emission reductions for each measure that met the methodology criteria. The DOE methodology targeted any key item where at least 15% of field observations did not meet the corresponding prescriptive code requirement and thus savings could be achieved through improved compliance. Potential annual energy cost savings by state ranges from a low of $1.2 million in Kentucky to a high of nearly $4.9 million in Texas. Combined, the seven original field study states exhibit the potential for over $18 million in annual savings through increased compliance with codes already in place.

Table 2.12 emphasizes the magnitude of energy cost savings that might be achieved in each state and the target measures contributing to those savings. Note that a straight comparison of savings potential across states is difficult because the respective estimates are heavily influenced by expected rates of new construction in each state. For example, Texas (CZ2a) is assumed to construct nearly two times as many homes per year as the next largest state (North Carolina). This also underscores the importance of achieving full compliance with codes in regions of high construction volume.

Table 2.12. Phase I Total Annual Energy Cost Savings Potential by State

State	Envelope Tightness	Duct Tightness	Wall Insulation	Ceiling Insulation	Lighting	Foundation	Window SHGC	**Total**
-PA	-	$1,360,493	$798,031	$499,392	$365,254	$175,676	-	**$3,198,846**
MD	$754,946	$146,619	$401,479	$44,366	$195,378	-	-	**$1,542,788**
KY	$484,314	$43,142	$171,044	$215,656	$197,544	$108,156	-	**$1,219,856**
NC	$211,315	$334,527	$390,827	$503,364	$520,839	$65,086	-	**$2,025,958**
GA	-	$685,683	$1,151,262	$1,880,668	$799,065	-	-	**$4,516,678**
AL	$263,089	$395,063	$201,105	-	$385,451	-	$54,674	**$1,299,382**
TX (CZ2a)	$654,623	$1,914,867	$511,748	$216,147	$1,550,412	-	-	**$4,847,797**
Total	**$2,368,287**	**$4,880,394**	**$3,625,496**	**$3,359,593**	**$4,013,943**	**$348,918**	**$54,674**	**$18,651,305**

Table 2.13 shows the average annual savings by measure for a typical home across all states studied. Looking at the potential savings on a per-home basis enables an equal comparison between states by normalizing the number of homes constructed. Thus, we see a much different hierarchy in terms of total potential savings, with Pennsylvania with the most per home potential energy savings and Texas among the states with the least. On a measure level basis, the energy impact of the levels of non-compliance observed in the histograms in Section 2.3 becomes readily apparent. Maryland and Kentucky, states with low envelope tightness compliance, show a $72 and $66 per home savings, respectively. Alternatively, North Carolina demonstrated high levels of envelope tightness compliance, yielding only $7 of potential savings per home.

Table 2.13. Phase I Average Annual Energy Cost Savings by Measure for a Typical Home

State	Envelope Tightness	Duct Tightness	Wall Insulation	Ceiling Insulation	Lighting	Foundation	Window SHGC	**Total**
PA	-	$93	$54	$34	$25	$12	-	**$218**

MD	$72	$14	$38	$4	$19	-	-	**$146**
KY	$66	$6	$23	$29	$27	$15	-	**$166**
NC	$7	$11	$13	$17	$17	$2	-	**$67**
GA	-	$25	$42	$68	$29	-	-	**$164**
AL	$28	$42	$21	-	$41	-	$6	**$137**
TX (CZ2a)	$12	$35	$9	$4	$28	-	-	**$88**

2.4 Cumulative Savings Potential

The energy cost, energy savings, and emission reduction potential in Table 2.14 through Table 2.16 demonstrate the need and opportunity associated with improved energy code compliance. These results indicate that if all non-compliant measures were brought up to full compliance, there is the potential to save over $8.6 billion and reduce emissions by over 208 MMT CO2e over 30 years.[15] The cumulative savings analysis keeps the following parameters constant across years to minimize variability and assess the cumulative impact of non-compliance with key items in Phase I.

1. Annual number of permits estimated for the state
2. Split of permits between climate zones in multi-climate zone states
3. Distribution of heating system types in the state
4. Distribution of foundation types in the state
5. Number of observations of key items per climate zone in multi-climate zone states used in the Monte Carlo simulations.

Table 2.14. Phase I 1-year, 5-year, 10-year, and 30-year Cumulative Annual Energy Cost Savings Potential

State	Annual Energy Cost Savings Potential ($)	5-Year Energy Cost Savings Potential ($)	10-Year Energy Cost Savings Potential ($)	30-Year Energy Cost Savings Potential ($)
PA	$3,198,846	$47,982,690	$175,936,530	$1,487,463,390
MD	$1,542,788	$23,141,820	$84,853,340	$717,396,420
KY	$1,219,856	$18,297,840	$67,092,080	$567,233,040
NC	$2,025,958	$30,389,370	$111,427,690	$942,070,470
GA	$4,516,678	$67,750,170	$248,417,290	$2,100,255,270
AL	$1,299,382	$19,490,730	$71,466,010	$604,212,630
TX (CZ2a)	$4,847,797	$72,716,955	$266,628,835	$2,254,225,605
Total	**$18,651,305**	**$279,769,575**	**$1,025,821,775**	**$8,672,856,825**

[15] The multi-year savings reflect the same reductions and increases as the annual savings and are simply the annual savings multiplied by 15, 55, and 465 for 5-year, 10-year, and 30-year savings, respectively. For analytical details refer to the methodology report (DOE 2018).

Table 2.15. Phase I 1-year, 5-year, 10-year, and 30-year Cumulative Energy Savings Potential

State	Potential Total Energy Savings (MMBtu)	5-Year Potential Total Energy Savings (MMBtu)	10-Year Potential Total Energy Savings (MMBtu)	30-Year Potential Total Energy Savings (MMBtu)
PA	195,563	2,933,445	10,755,965	90,936,795
MD	93,341	1,400,115	5,133,755	43,403,565
KY	62,508	937,620	3,437,940	29,066,220
NC	90,877	1,363,155	4,998,235	42,257,805
GA	161,300	2,419,500	8,871,500	75,004,500
AL	45,849	687,735	2,521,695	21,319,785
TX (CZ2a)	207,066	3,105,990	11,388,630	96,285,690
Total	**856,504**	**12,847,560**	**47,107,720**	**398,274,360**

Table 2.16. Phase I 1-year, 5-year, 10-year, and 30-year Cumulative Annual Emissions Reduction Potential

State	Annual Emissions Reduction Potential (MT CO2e)	5-Year Emissions Reduction Potential (MT CO2e)	10-Year Emissions Reduction Potential (MT CO2e)	30-Year Emissions Reduction Potential (MT CO2e)
PA	48,525	727,875	2,668,875	22,564,125
MD	7,469	112,035	410,795	3,473,085
KY	7,653	114,795	420,915	3,558,645
NC	73,605	1,104,075	4,048,275	34,226,325
GA	121,936	1,829,040	6,706,480	56,700,240
AL	7,569	113,535	416,295	3,519,585
TX (CZ2a)	181,047	2,715,705	9,957,585	84,186,855
Total	**447,804**	**6,717,060**	**24,629,220**	**208,228,860**

3.0 Phase II Activities

In Phase II, the state project teams focused on the measures with the largest savings potential in their state, with the goal of increasing compliance. This was done by first understanding the key areas of non-compliance identified in Phase I and developing an effective training and education program. The individual state project teams chose the best strategies for each state and conducted various education and training activities ranging from traditional classroom-based training to more advanced online or onsite methods. These activities were conducted amongst a broad range of stakeholders, including state agencies, regional and trade organizations, academia, etc. The training and education phase of this study lasted approximately 2 years for each state. Strategies can be categorized into six main groups: classroom training, online training, circuit rider, direct mail, hotline, and technical resources. These broad strategies and specific state examples are noted in Table 3.1.

Table 3.1. Example Education, Training, and Outreach Activities (Phase II)

Classroom Training	Online Training	Circuit Rider	Direct Mail	Hotline	Technical Resources
High-level building science and code training	Energy code quizzes and other learning assessments	Training and technical resources distributed at job sites	Infographics highlighting key areas mailed to trades and code officials	Phone hotlines to assist with common code questions	Photo libraries demonstrating compliant and non-compliant practices
Specific training for different stakeholders (inspectors, builders, architects)	Tech tips focused on specific applications (e.g., knee walls)	Live demonstrations at trade shows and industry events	Quarterly newsletters	Online assistance with a response within 24 hours	Infographics and educational materials targeting key requirements (e.g., ducts)
In-depth training on common compliance challenges (air sealing, IIQ, duct sealing)	Videos (of training) and animation of various code requirements	Energy code ambassador programs	Direct letters mailed to code officials demonstrating the need for improved compliance	Energy code coach	Energy code books, code compliance guides, and energy compliance stickers
Hands-on training on duct and envelope tightness	Energy Center Live – Series of five videos with sports commentator theme and humor covering code target areas	In-office training sessions hosted at building departments	Postcard highlighting health and safety risks of leaky ducts	Project websites developed to make resources available	Energy code measure cheat sheets

One of the unique aspects of this study is comparing education and training approaches by state. Although each state implemented similar strategies as outlined in Table 3.1, the relative use of each strategy differed considerably. Figure 3.1 highlights the percentage of attendees engaged per education and training strategy within each state. Many of the states involved roughly half of the program participants through in-person classroom training, ranging from half-day to full-day classes taught by qualified energy code instructors. However, the type of content and approach to training—some more hands-on, others focused on the building science behind energy code requirements—differed among states. In addition to in-person classroom training, the two other critical components to many programs within each state included online training and the use of a circuit rider. A circuit rider is an individual with subject matter expertise who mobilizes to serve multiple jurisdictions across a given geographic area (e.g., providing insight, knowledge, and training on compliance best practices). Georgia, Kentucky, Maryland, Pennsylvania, and North Carolina all included some version of a circuit rider to educate on the state energy code.

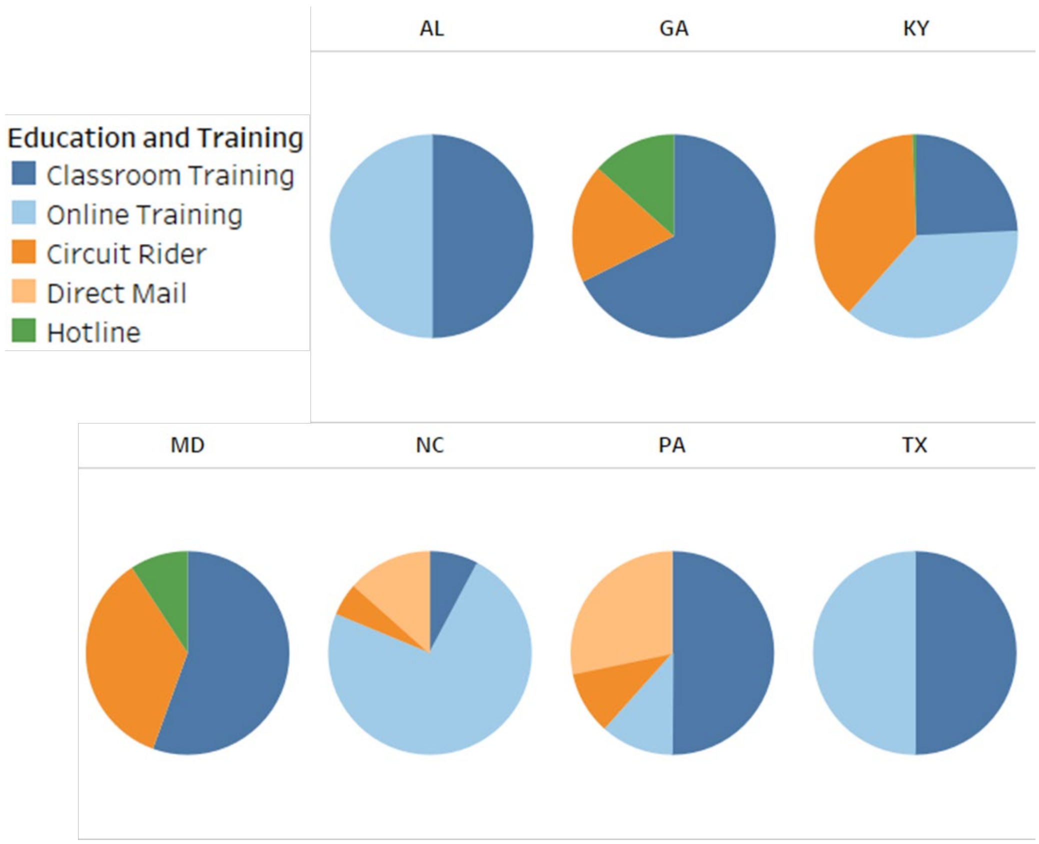

Figure 3.1. Phase II Education, Training, Outreach by State (Percentage of Attendees)[16]

All states reported the number of attendees engaged except for Alabama, which provided a more qualitative assessment of its education and training efforts. A breakdown of total attendees reached by category and state is in Table 3.2. States that prioritized online training and direct mail, like North Carolina, were able to reach a significant number of people; however, the extent to which those people engaged with and utilized the materials is unknown. A more concrete way to ensure the training concepts were passed on to program participants was through in-person classroom training or a circuit rider. All

[16] Technical resource development and dissemination are not considered within a separate education and training category in Figure 3.1 because technical resources were disseminated throughout each component of the program.

project teams offered in-person classroom training and consistently engaged between 500–1,000 people over the Phase II timeline. States that employed a circuit rider found success in reaching individuals that normally would not attend in-person training events. As described in a follow-up report on the Kentucky study, “the intent was for the circuit rider to become a trusted advisor on energy code issues. This intent was then reinforced by the circuit rider making return visits to offer more detailed and in-depth assistance” (Burgess and Nagpal 2018). Several states (GA, KY, MD) established a hotline that industry could call with specific questions about the state energy code. Although this type of service is beneficial, the use was limited.

Table 3.2. Phase II Education, Training, Outreach by State (# of Participants)

State	Classroom Training	Online Training	Circuit Rider	Hotline	Direct Mail
Alabama	-	-	-	-	-
Georgia	606	-	170 [(a)]	120	-
Kentucky	424	650	662	10	-
Maryland	905	-	575	150	-
North Carolina	845	8,000	580	-	1,460
Pennsylvania	887	204	179	-	500
Texas	925	925	-	-	-
Total	4,592	9,779	1,996	280	1,960

(a) The Georgia team mentioned the circuit rider engaged 17 jurisdictions but did not include the exact number of participants. For comparison sake, we assumed 10 participants per jurisdiction were engaged.

Prioritization of key measures for education and training per state was derived from Phase I potential energy and cost savings results. Figure 3.2 highlights the relative savings potential of non-compliant measures that influenced the level and the type of training and education strategies employed within a given state. Focusing on measures with the most savings helps ensure the maximum return on investment for education and training activities and other compliance improvement programs.

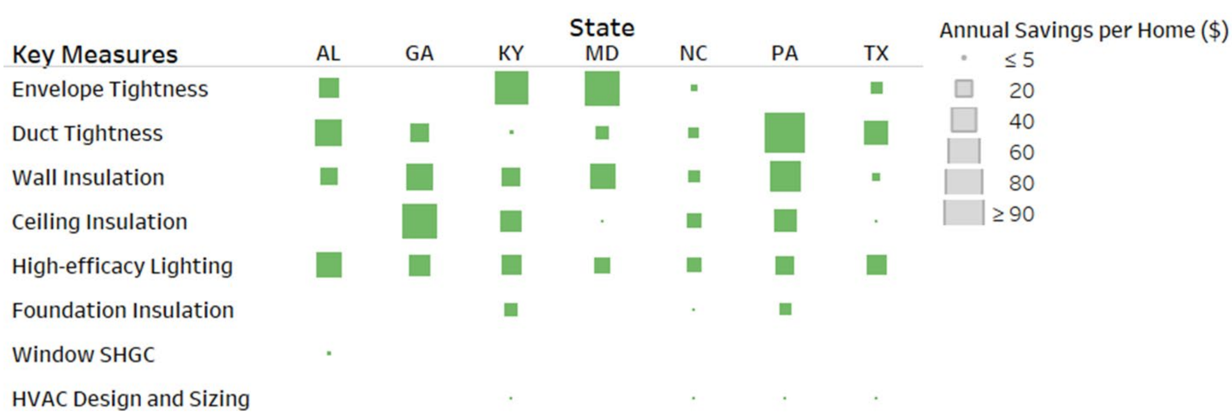

Figure 3.2. Phase I Non-compliant Measures Weighted by Annual Energy Savings Per Home ($)

All states prioritized and provided training on duct tightness, wall insulation, and high-efficacy lighting due to potential energy savings from improved code compliance. Ceiling insulation was heavily prioritized in Georgia as that was the most significant opportunity for savings in the state. Envelope tightness demonstrated the most significant savings opportunity for Kentucky and Maryland, and moderate savings for three other states. Even though not all states had the potential for savings with this measure, all teams provided education and training on envelope tightness, given it is a key foundational element to understanding and implementing building science principles. Other measures, such as foundation insulation and window SHGC requirements, demonstrated lower potential savings in a few states, and thus, fewer resources were dedicated to training on those measures.

Four of the states (KY, NC, PA, TX) identified HVAC design and sizing as an opportunity for training and education. The methodology did not establish HVAC design and sizing as one of the key measures but did recommend collecting these data in Phase I if it were available. Specific project teams, such as Kentucky, collected HVAC sizing data and found that many HVAC systems were significantly oversized. The code requires HVAC systems be sized according to Air Conditioning Contractors of America (ACCA) Manual J, so significant oversizing likely indicates reduced compliance with this measure. Studies have shown that oversized HVAC systems have a greater peak energy demand and shorter system run times, thereby increasing overall utility peak power use and limiting the ability to remove moisture in the home (Rhodes et. al 2011). Curriculum and technical resources were developed in these states to educate stakeholders on the importance of right-sizing HVAC equipment.

4.0 Summary of Phase III Results

A summary of the Phase III results is provided for all seven states that completed the original FOA. A Phase III report was published for each state,[17] including three sets of results: distributions of key item observations, comparison of average expected and observed EUIs, and measure level savings potential. Table 4.1 provides the Phase I and Phase III observed EUIs for each state and the EUI and percent difference when comparing the two phases. A positive percent change indicates the EUI increased from Phase I to Phase III, where a negative number indicates an improvement. Table 4.2 shows the average measure level change in code compliance from Phase I to Phase III. Improvement in a measure level compliance rate from Phase I to Phase III is represented with a positive number, where a reduction in compliance is represented with a negative number.

Table 4.1. Phase I to Phase III Change in Average Statewide Energy Use by State

State	Baseline Code	Observed EUI (kBtu/sf)		Differential (Phase I vs. III) [a]	
		Phase I	Phase III	EUI (kBtu/ft^2)	Difference (%)
PA	2009 IECC	40.73	43.70	2.97	7%
MD	2015 IECC	30.49	27.51	-2.98	-10%
KY	2009 IECC	31.31	29.49	-1.82	-6%
NC	2012 NC Code	22.96	23.26	0.30	1%
GA	2011 GA Code	26.52	24.48	-2.04	-8%
AL	2015 AL Code[b]	19.81	19.04	-0.77	-4%
TX (CZ2a)	2015 IECC	22.57	20.74	-1.83	-8%

(a) A reduction in EUI from Phase I to Phase III indicates buildings are more efficient or average, thus a negative number in the differential columns represents improvement.
(b) Alabama updated its energy code in the timeframe between Phases I and III of the study (2009 to 2015 AL Code).

Table 4.2. Phase I to Phase III Change in Average Statewide Measure Level Compliance Rates

State	Envelope Tightness[a]	Duct Tightness	Wall Insulation U-factor	Ceiling Insulation U-factor	Lighting	Window U-factor	Window SHGC
PA	-7%	-15%	+17%	-33%	+32%	0%	-
MD	+11%	+26%	+1%	+25%	+35%	+2%	-
KY	+27%	-14%	+10%	+30%	+4%	-2%	-
NC	-12%	-12%	+53%	+7%	+13%	+1%	0%
GA	+4%	+10%	+4%	+49%	+46%	0%	+1%
AL	+5%	-7%	0%	+13%	+16%	+6%	+13%
TX (CZ2a)	+32%	+65%	+3%	-16%	+50%	-4%	+2%

[17] All Phase III reports are available at https://www.energycodes.gov/compliance/energy-code-field-studies.

(a) Table 4.2 represents the differential in compliance rates for each measure. A positive number in each column indicates compliance improved for a particular measure and thus buildings became more efficient on average.

Phase III demonstrated improved measure level compliance rates across measures in most states. This resulted in an improvement (reduction) in the average EUI across five out of the seven states and potential savings in all but one state. On a measure level basis, compliance rates for high-efficacy lighting improved across all states, some rather significantly. Compliance rates improved for frame wall insulation (U-factor) in all but one state, although significant savings opportunity remains. Ceiling insulation (U-factor) compliance improved in all but two states, which was driven in large part to better IIQ. Despite the success of the Phase II education and training program, collectively, a potential savings of $10.6 million annually remains after Phase III that can be captured through improved compliance.

4.1 Phase I and III Field Observations

A post-training field study was conducted following the same methodology employed in Phase I. Sixty-three sets of key item data were gathered in each state to provide a meaningful comparison to Phase I and determine the effectiveness of Phase II education and training. Data collected in Phase III serve as the basis for conducting the same statistical analysis of key item observations, comparison to prescriptive (code baseline) and Phase I EUIs, and measure level savings potential.

The following subsections contain graphs and charts that highlight the state averages, distribution of observations compared to code measure, and the relative compliance rate for each key measure compared across the seven states. Comparisons are drawn between the following relevant measures across all states:

1. Envelope tightness (ACH at 50 Pascals)
2. Windows (U-factor and SHGC)
3. Wall insulation (R-value and assembly U-factor)
4. Ceiling insulation (R-value and assembly U-factor)
5. Lighting (% high-efficacy)
6. Foundation insulation (R-value and assembly U-factor)[18]
7. Duct tightness (cfm per 100 ft^2 of conditioned floor area at 25 Pascals).

4.1.1 Envelope Tightness

Figure 4.1, Figure 4.2, and Table 4.3 present the envelope tightness results for Phase I and III.

[18] Floor insulation, basement wall insulation, crawlspace wall insulation, and slab insulation are combined into a single category of foundation insulation. A comparison of types and insulation levels is found in Appendix A.

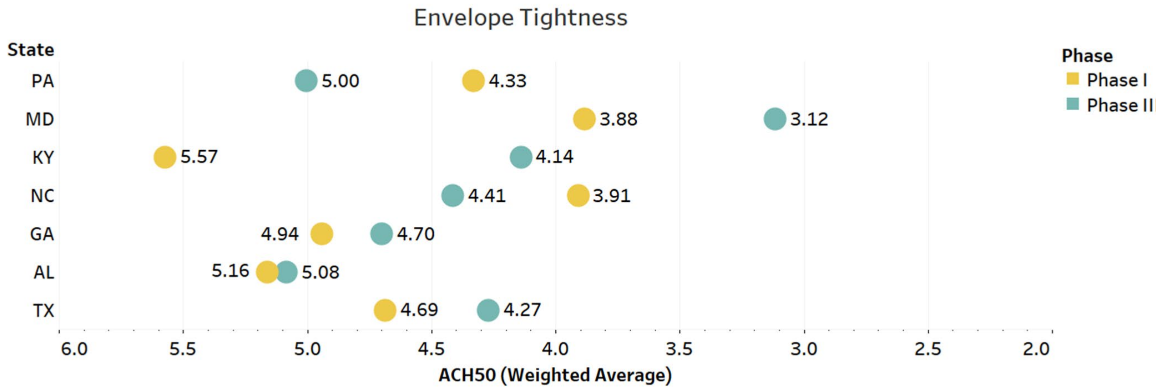

Figure 4.1. Average Envelope Tightness Phase I and Phase III

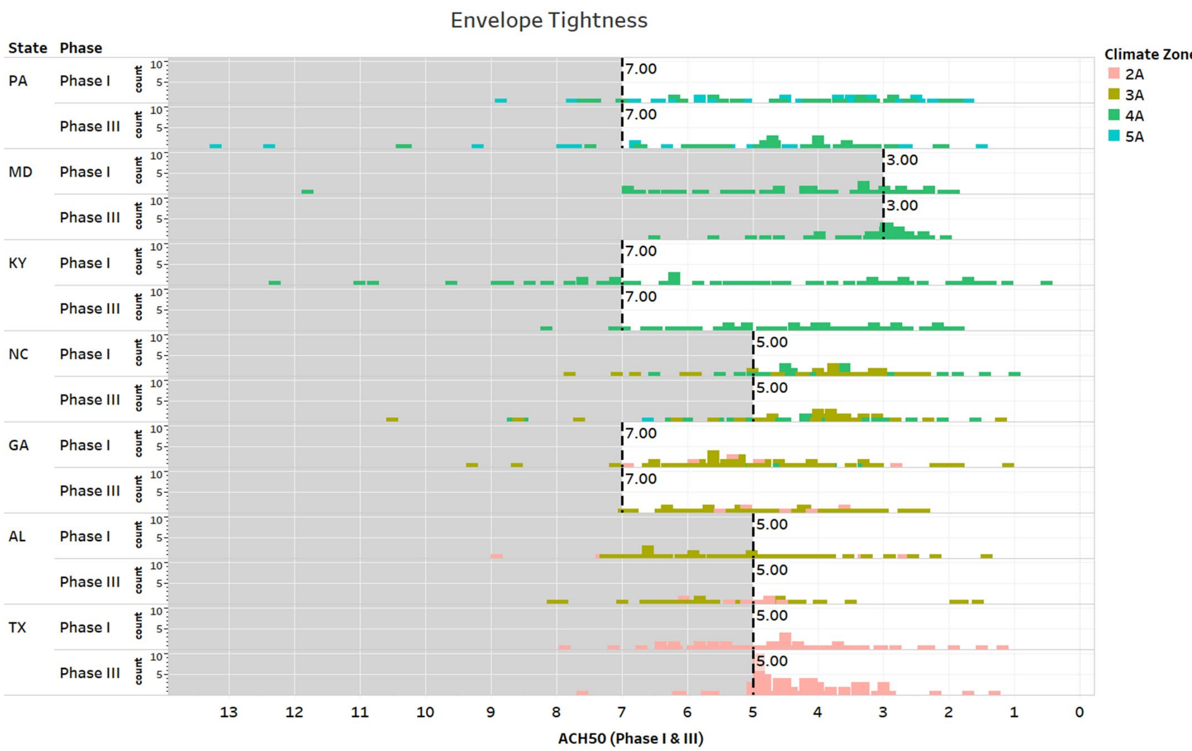

Figure 4.2. Envelope Tightness Phase I and Phase III Comparison[19]

Table 4.3. Phase I and Phase III Envelope Tightness Compliance Rate

State	Code Requirement	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Pennsylvania	7 ACH50	65 of 70 (93%)	54 of 63 (86%)	-7%
Maryland	3 ACH50	34 of 63 (54%)	46 of 71 (65%)	+11%
Kentucky	7 ACH50	46 of 66 (70%)	61 of 63 (97%)	+27%
North Carolina	5 ACH50	59 of 67 (88%)	48 of 63 (76%)	-12%

[19] Kentucky had three Phase I observations at 15.6, 18.5 and 20 that are not shown on this graph.

State	Code Requirement	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Georgia	7 ACH50	70 of 73 (96%)	68 of 68 (100%)	+4%
Alabama	5 ACH50	30 of 65 (46%)	32 of 63 (51%)	+5%
Texas	5 ACH50	39 of 65 (60%)	60 of 65 (92%)	+32%

Per the methodology, envelope tightness testing is required in all states conducting a compliance study regardless of whether the respective state code required it or not. For instance, in Pennsylvania and Kentucky envelope tightness testing is an optional method to demonstrate compliance with their codes' air sealing and insulation section. Given that builders in these states may not be accustomed to having this type of test performed on their homes, this is important context when comparing states on this measure.

- **Interpretations**:
  - Improvement in envelope tightness was displayed in all states except Pennsylvania and North Carolina, where the state averages and compliance rates were better in Phase I. Other states had improvements in the average range from .08 ACH50 in Alabama to nearly 1.5 ACH50 in Kentucky. The average ACH50 across both phases and states is 4.5, indicating the majority of homes are constructed with envelope tightness in mind, even though states on the 2009 IECC, like Kentucky, do not require a blower door test. It should be noted that the IRC requires whole home mechanical ventilation in houses with an air leakage rate of 5 ACH50 or less, thus many of the homes in this study should be equipped with mechanical ventilation. Although ventilation was not a key measure within the study, some data on the type of ventilation system installed was collected and a comparative analysis between envelope tightness and installed mechanical ventilation systems in homes is discussed in the Additional Analysis section of this report.
  - As displayed in Table 4.3, Kentucky and Texas had the most significant improvement in code compliance ranging from 27% to 32%, respectively. As discussed in Section 3.0, Phase II Activities, education and training on envelope tightness strategies were provided across all states, regardless of the compliance rate in Phase I.

4.1.2 Duct Tightness (Adjusted)

Figure 4.3, Figure 4.4, and Table 4.4 show the duct tightness (adjusted) results for Phase I and III.

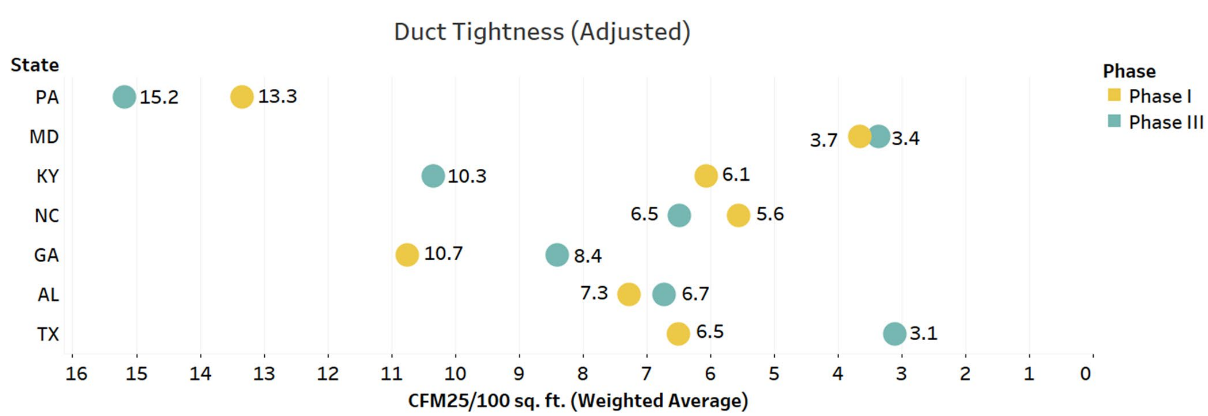

Figure 4.3. Average Adjusted Duct Tightness Phase I and Phase III

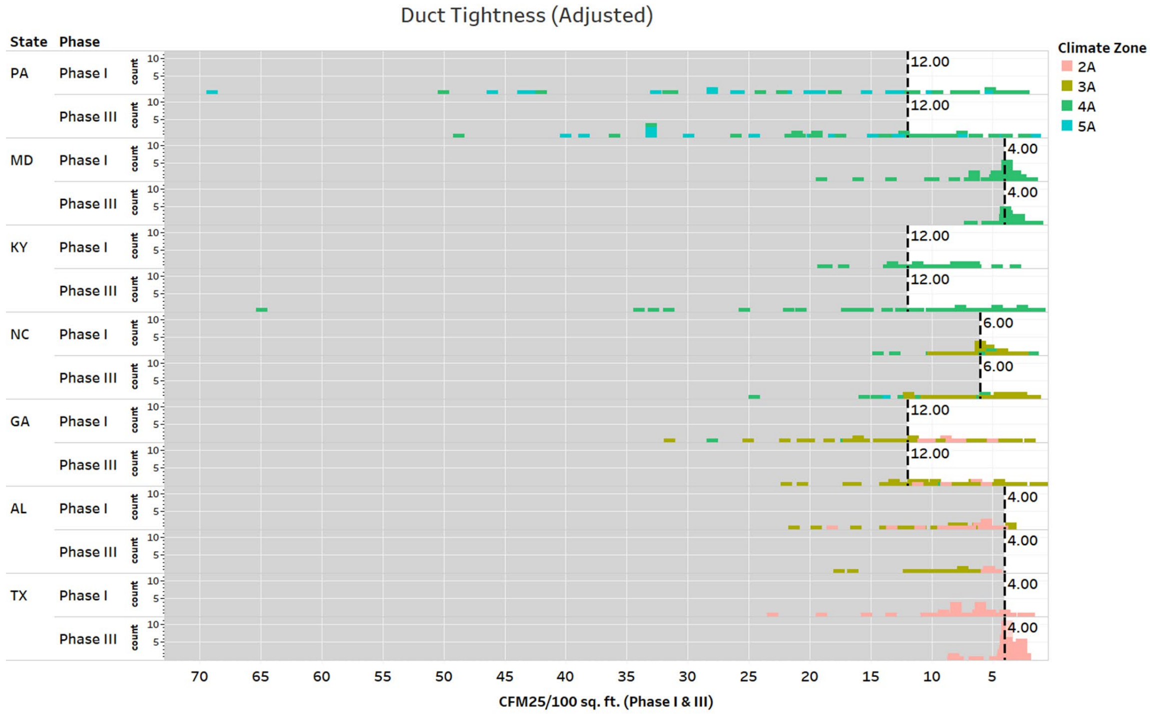

Figure 4.4. Adjusted Duct Tightness Phase I and Phase III Comparison[20]

Table 4.4. Phase I and Phase III Adjusted Duct Tightness Compliance Rate

State	Code Requirement (cfm25/100 ft^2)	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Pennsylvania	12.0	44 of 70 (63%)	31 of 65 (48%)	-15%
Maryland	4.0	49 of 79 (62%)	70 of 80 (88%)	+26%
Kentucky	12.0	31 of 40 (77%)	33 of 52 (63%)	-14%
North Carolina	6.0	43 of 67 (64%)	41 of 79 (52%)	-12%
Georgia	12.0	48 of 70 (69%)	54 of 68 (79%)	+10%
Alabama	4.0	11 of 75 (15%)	6 of 75 (8%)	-7%
Texas	4.0	12 of 64 (19%)	75 of 89 (84%)	+65%

The IECC requires that the duct system be tested for leakage if any part of the system is not entirely within conditioned space; however, all ducts were tested as part of this protocol. As a result, two sets of data are presented, duct leakage adjusted – only considering observations with ducts outside of conditioned space – and duct leakage unadjusted – considering all duct leakage observations.

- **Interpretations**:
  - Duct tightness was more of a compliance challenge than envelope tightness in Phase I. As a result, most states provided training on the topic. Interestingly, five out of the seven states

[20] Kentucky had one Phase III observation at 185 that is not shown on this graph. Additionally, although in the analysis we set adjusted values of ducts entirely in conditioned space to 0, to better demonstrate data trends we have excluded the observations that were set to 0 from this graph. A total of 146 observations across all states were set to 0 and excluded from this graph.

demonstrated a reduction in leakage rate on average, with Kentucky and North Carolina not showing improvement. However, as shown in Table 4.4 the compliance rate actually decreased in four states (PA, KY, NC, AL), indicating that although on average, leakage rates improved, more observations fell on the left side of the compliance line in Phase III for these states. This trend is most noticeable in Alabama in Figure 4.4 where the distribution of observations becomes tighter around 4 cfm25/100 ft^2 in Phase III, but most of the observations were on the left side (non-compliant) of the line.

– Texas observed a significant reduction in duct leakage, with the average moving from 7 to 3.8 cfm25/100 ft^2. This resulted in a 65% improvement in the compliance rate. Surprisingly, two of the three states (TX, MD) with the most stringent duct leakage rates had the highest compliance rates in Phase III and saw the most significant improvement across all states.

4.1.3 Duct Tightness (Unadjusted)

Figure 4.5 and Figure 4.6 compare the average and distribution of unadjusted duct tightness rates, including all homes that received a duct blaster test, not just those with ducts outside conditioned space.

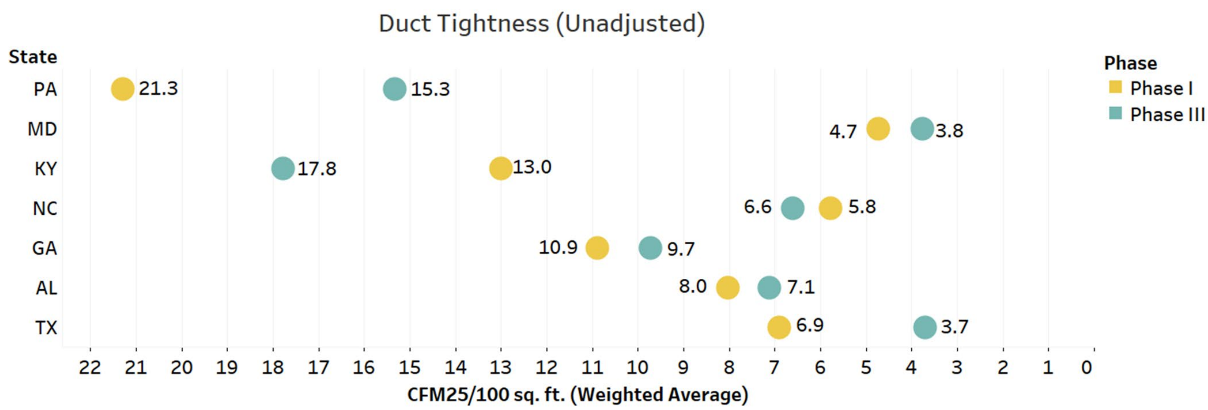

Figure 4.5. Average Unadjusted Duct Tightness Phase I and Phase III

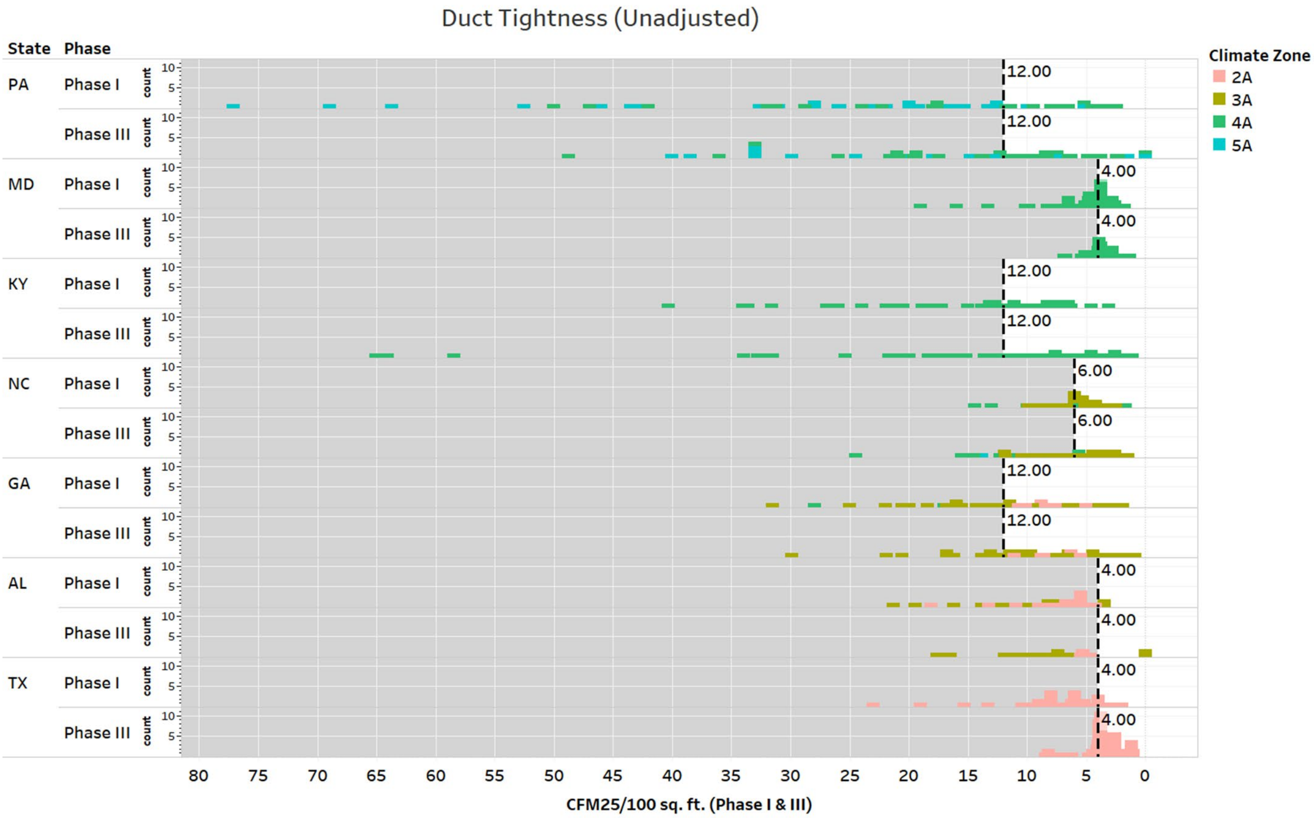

Figure 4.6. Unadjusted Duct Tightness Phase I and Phase III Comparison[21]

- . **Interpretations**:
  - The unadjusted duct leakage rates improved on average in all states except Kentucky and North Carolina. Interestingly, Pennsylvania demonstrated improvement in the unadjusted but not the adjusted rate in Phase III. This could indicate that more care was taken to seal systems with ducts entirely within conditioned space.
  - In most states, the average unadjusted duct tightness rate was similar or even slightly better than the adjusted rates. However, this was not the case for Kentucky and Pennsylvania Phase I, where the average unadjusted rates were considerably higher than the adjusted rates. Kentucky and Pennsylvania exhibited high leakage rates for duct systems entirely within conditioned space.[22]
  - The distribution of unadjusted duct tightness observations displays a larger tail to the left side of the graph in Figure 4.6, indicating some of the additional duct tightness observations were homes with all ducts in conditioned space and tested at a high leakage rate.

4.1.4 Frame Wall Insulation

In certain climate zones, the code allows for two prescriptive options for wall insulation (e.g., R-20 or R-13+5 continuous). The energy performance of a wall insulation system is determined both by the R-value

[21] Kentucky had two Phase III observations at 185 and 122.5 that are not shown on this graph.
[22] Additional explanation of this trend is found in Section 4.2 and state level data on duct tightness in conditioned space is in Appendix A.2 of this report.

of the cavity and continuous insulation installed and the quality of the installation in the cavity. Figure 4.7, Figure 4.8, Figure 4.9, and Figure 4.10 show results that account for the different combinations of wall assemblies.

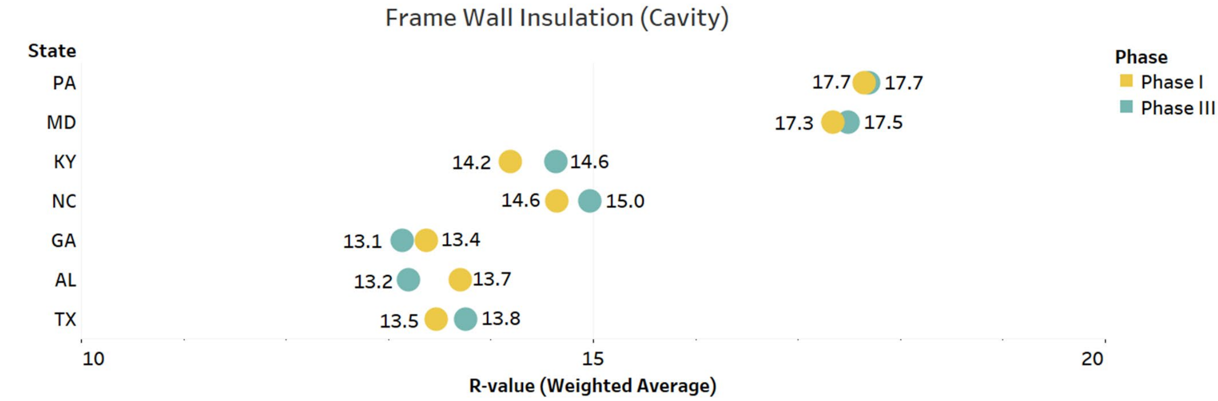

Figure 4.7. Average Frame Wall Cavity Insulation Phase I and Phase III

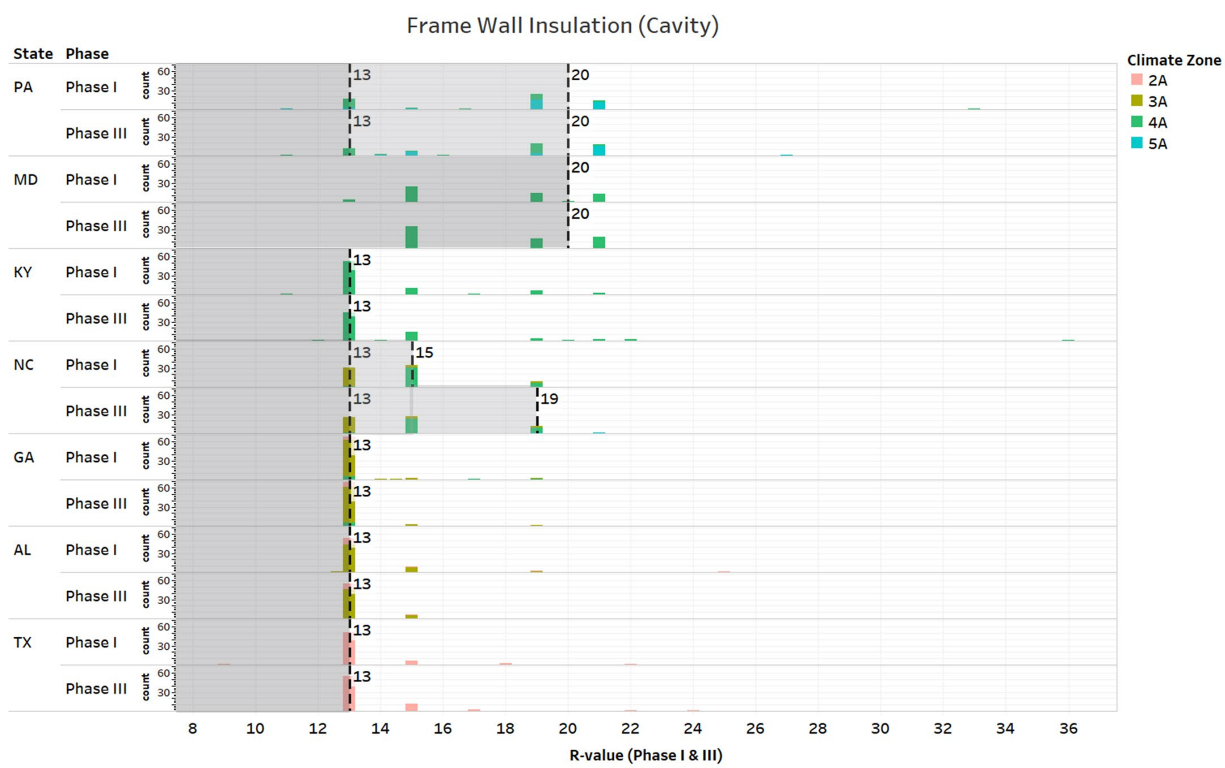

Figure 4.8. Frame Wall Cavity Insulation Phase I and Phase III Comparison

Figure 4.7 and Figure 4.8 display the average frame wall cavity insulation levels and compliance levels compared to each state's prescriptive cavity-only insulation requirement. This comparison provides a good understanding of prescriptive R-value compliance for states like Alabama and Georgia, which did not have any wall assemblies with continuous insulation.

- **Interpretations**:
  - When only looking at cavity insulation, most observations meet or exceed the prescriptive cavity-only requirement. This is clearly demonstrated in states with a cavity-only R-value requirement of R-13 but does not provide an accurate accounting of R-value compliance in states with high rates of continuous insulation, such as Maryland.

To get an accurate sense of R-value compliance for all states, continuous insulation must be considered. Figure 4.9 compares wall assemblies for the five states with cavity and continuous wall insulation.

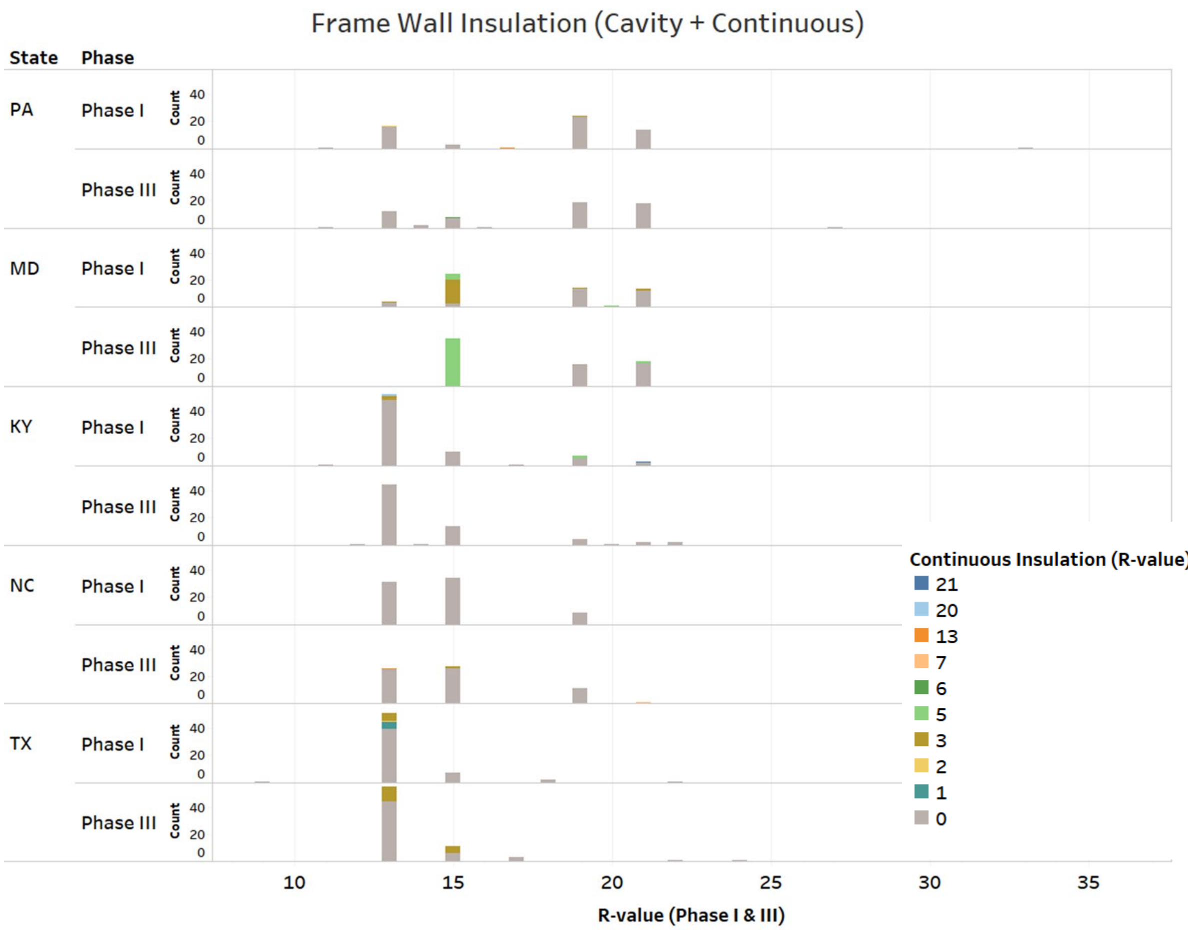

Figure 4.9. Frame Wall Cavity & Continuous Insulation Phase I and Phase III Comparison

- **Interpretations**:
  - Most states had very few instances of cavity and continuous wall assemblies. Maryland was the one state where the market seems to embrace continuous insulation. One reason for this could be because a cavity and continuous insulation option is not included in the prescriptive table in the Kentucky, North Carolina, Georgia, Alabama and Texas state codes.
  - Texas was the state with the second most observations of cavity and continuous insulation assemblies. Given their warm climate zones, this is a surprising finding and could have led to improved envelope tightness.

With the high use rate of continuous insulation in Maryland, wall assembly data provide a great example of how continuous insulation impacts prescriptive code compliance. Figure 4.10 is a multidimensional graph with cavity insulation on the x-axis and continuous insulation on the y-axis. The number of observations for each are labeled and weighted according to circle size. In Phase I, we find 18 observations of wall assemblies with R-15 +3, which does not meet the prescriptive code requirement of R-13+5. This was identified as a key non-compliance issue in Phase I, so training was provided on code-compliant wall assemblies. Training appeared to have paid off as all cavity + continuous assemblies met the prescriptive code in Phase III with R-15 + 5 being predominant.

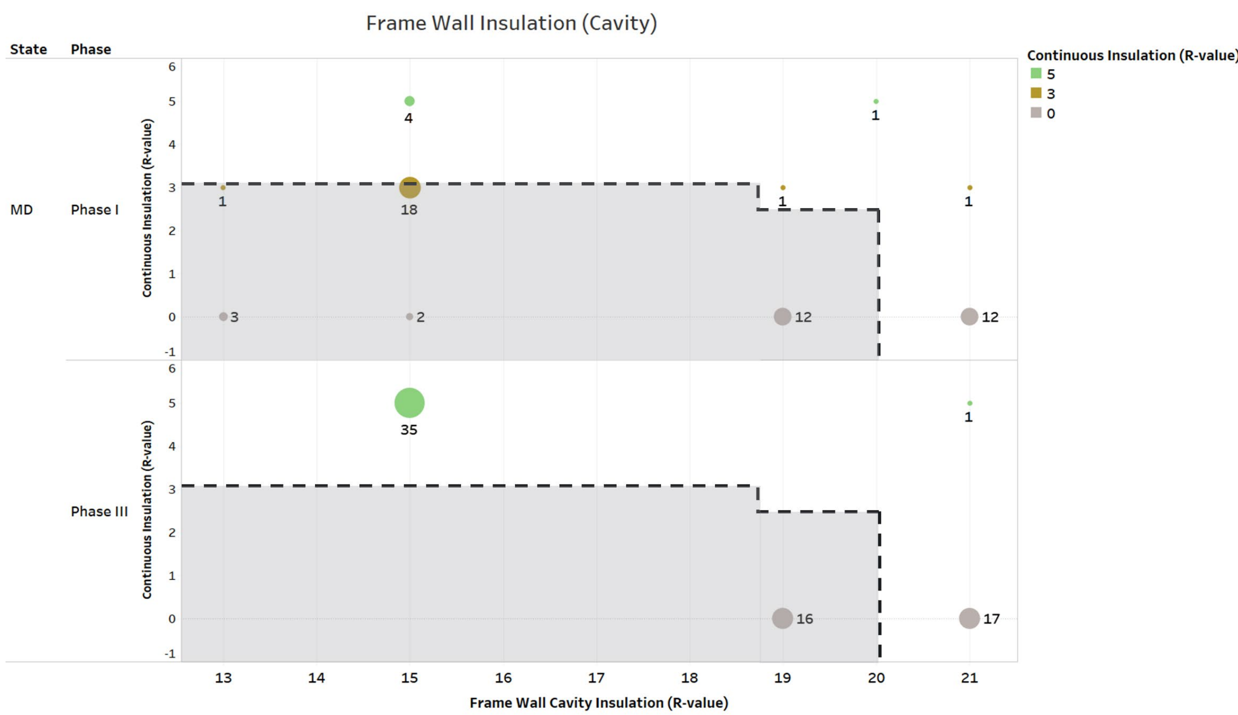

Figure 4.10. Maryland Phase I & III Cavity and Continuous Multidimensional Plot

4.1.5 Frame Wall IIQ

To accurately assess the efficiency of a wall assembly, IIQ must be considered. Teams followed the RESNET assessment protocol for cavity insulation which has three grades; Grade I indicating the best quality installation and Grade III indicating the worst. Figure 4.11 shows the percentage of IIQ observations by grade across all states for Phase I and Phase III.

	State / Phase													
	PA		MD		KY		NC		GA		AL		TX	
Wall Cavity Insulation (IIQ)	PI	PIII	PI	PIII	PI	PIII	PI	PIII	PI	PIII	PI	PIII	PI	PIII
I	32%	3%	59%	100%	35%	33%	45%	55%	14%	19%	12%	13%	61%	59%
II	65%	97%	38%		52%	63%	55%	40%	37%	50%	77%	87%	31%	38%
III	3%		4%		13%	4%		5%	49%	31%	11%		8%	3%

Figure 4.11. Frame Wall Cavity IIQ Phase I and Phase III

- **Interpretations**:
  - Wall cavity IIQ was a concern across all states in Phase I, with the percentage of Grade I observations ranging from 12% to 61% and Grade III from 3% to 49%.
  - Wall cavity IIQ improved considerably in Maryland, moving from 59% to 100% Grade I installation from Phase I to Phase III. Other states, such as Kentucky, Georgia, Alabama, and Texas saw a noticeable shift from Grade III to Grade II installs.
  - Wall cavity IIQ continues to be an area ripe for improvement, even after education and training on the topic in Phase II.

4.1.6 Frame Wall Insulation (U-factor)

To fully assess the impact wall assembly components and the IIQ have on wall system performance, a U-factor must be calculated for the wall assembly. Figure 4.12, Figure 4.13 and Table 4.5 describe the average distribution of observations compared to code and the compliance rates across all states and phases. Wall U-factors provide a consistent metric to assess wall assembly code compliance and estimate potential lost energy savings. U-factors include the R-value cavity insulation, the IIQ of that insulation, and any continuous insulation installed.

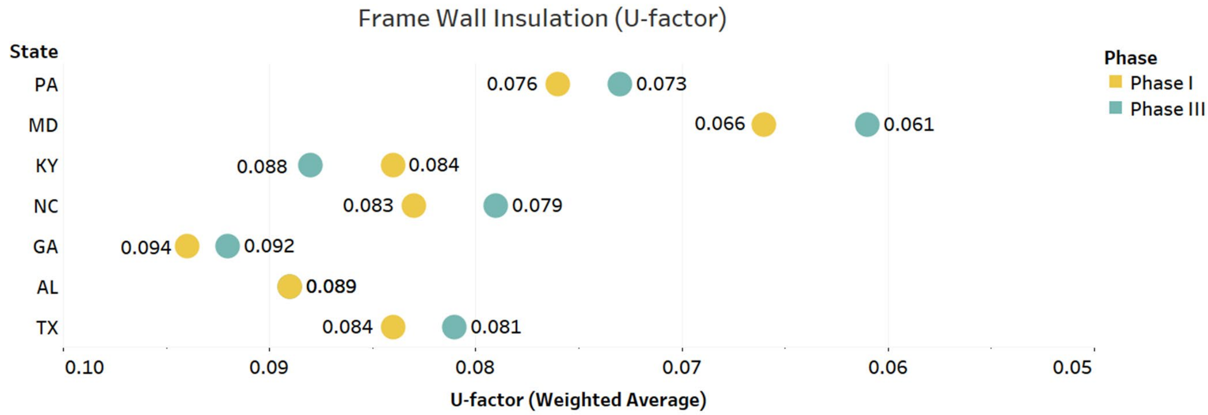

Figure 4.12. Average Frame Wall Insulation U-factors Phase I and Phase III[23]

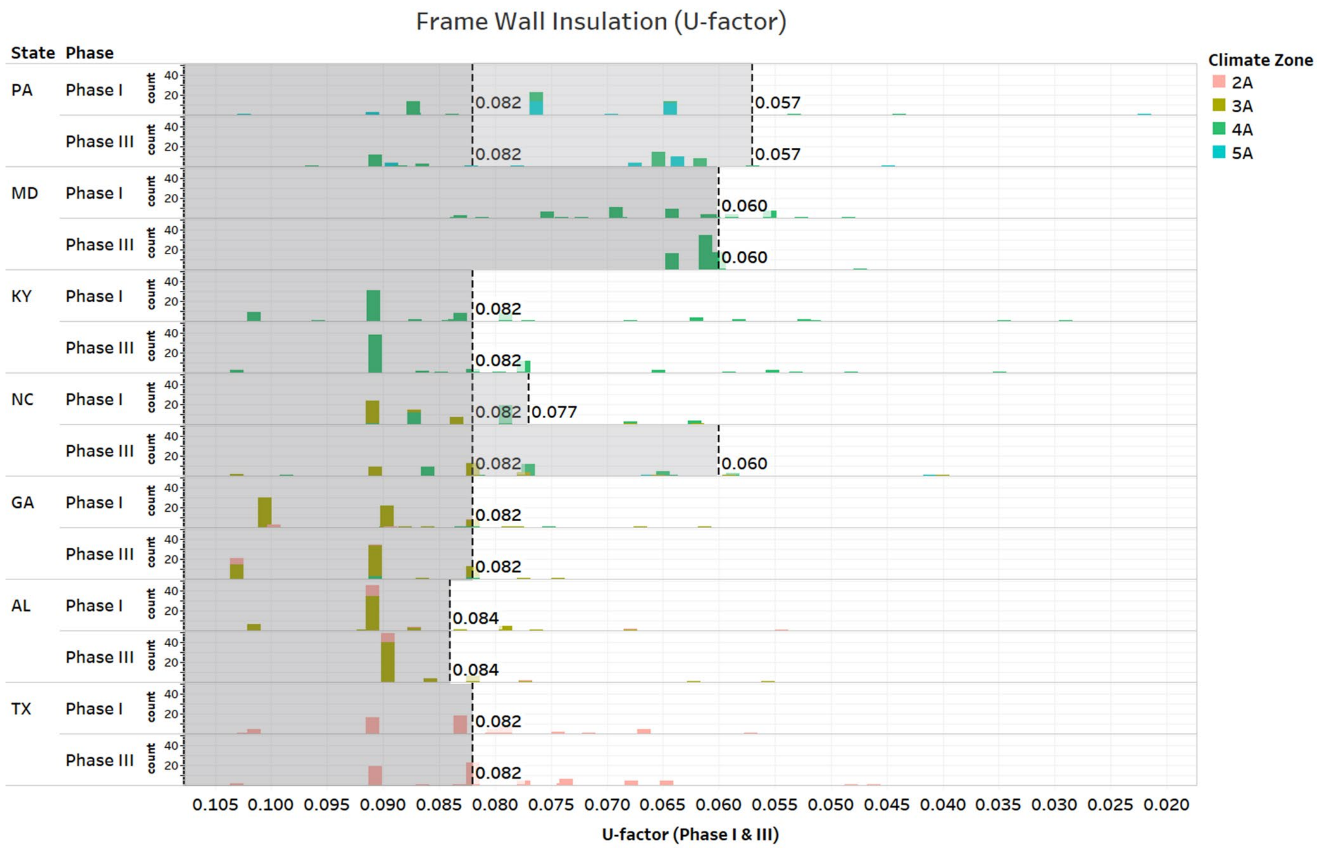

Figure 4.13. Frame Wall Insulation U-factors Phase I and Phase III Comparison

[23] Alabama had the same average frame wall insulation U-factor in Phase I and Phase III, so only one dot is displayed in Figure 4.12.

Table 4.5. Phase I and Phase III Frame Wall Insulation U-factors Compliance Rate

State	Code Requirement (U-factor)	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Pennsylvania	0.082 (CZ4) 0.057 (CZ5)	14 of 62 (23%)	25 of 62 (40%)	+17%
Maryland	0.060	14 of 56 (25%)	18 of 69 (26%)	+1%
Kentucky	0.082	21 of 75 (28%)	27 of 71 (38%)	+10%
North Carolina	0.082 (CZ3) 0.077 (CZ4) 0.060 (CZ5)	9 of 74 (12%)	42 of 65 (65%)	+53%
Georgia	0.082	13 of 76 (17%)	15 of 72 (21%)	+4%
Alabama	0.084	11 of 68 (16%)	10 of 63 (16%)	0%
Texas	0.082	40 of 62 (65%)	48 of 71 (68%)	+3%

- **Interpretations**:
  - All states except Kentucky saw an improvement in the average U-factor when considering all observations within each state. Despite this reduction in the weighted average, Kentucky still demonstrated a 10% improvement in compliance rate from Phase I to Phase III.
  - Maryland demonstrated the largest improvement in average U-factor compared to the other states but only saw a 1% increase in their compliance rate. This finding can be easily identified in Figure 4.13, as the distribution of observations becomes much tighter around the prescriptive compliance measure of 0.06 but remains on the non-compliant (left) side of the line.
  - North Carolina saw the most improvement in its compliance rate by a wide margin (53%). However, at 65% compliance, there is still the opportunity for savings.
  - There is considerable opportunity for improved compliance and savings across all states.

4.1.7 Ceiling Insulation (R-value)

Unlike wall insulation, ceiling insulation has one prescriptive code requirement option per state and climate zone. This provides the opportunity to easily compare insulation in terms of R-value, IIQ, and U-factor separately and compare it to the code. Figure 4.14, Figure 4.15, and Table 4.6 compare the ceiling R-value observations across states.

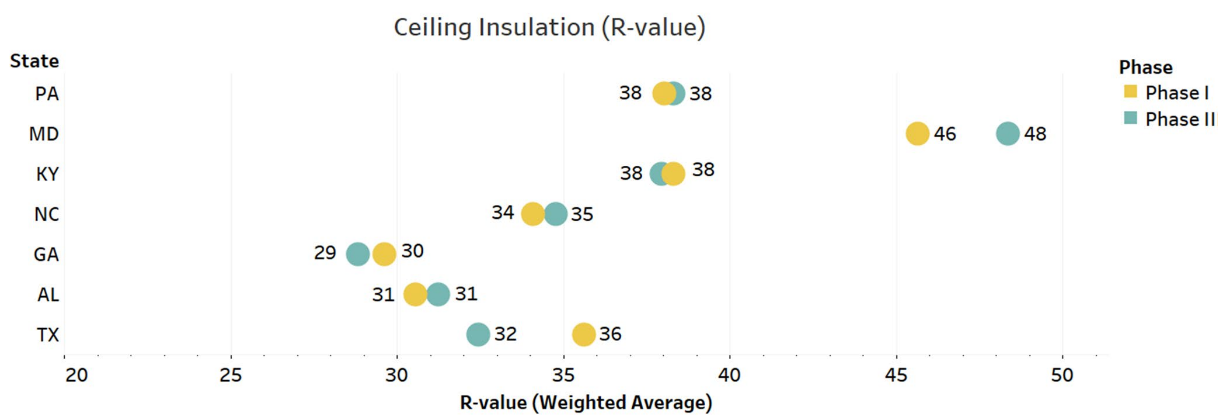

Figure 4.14. Average Ceiling Insulation R-values Phase I and Phase III

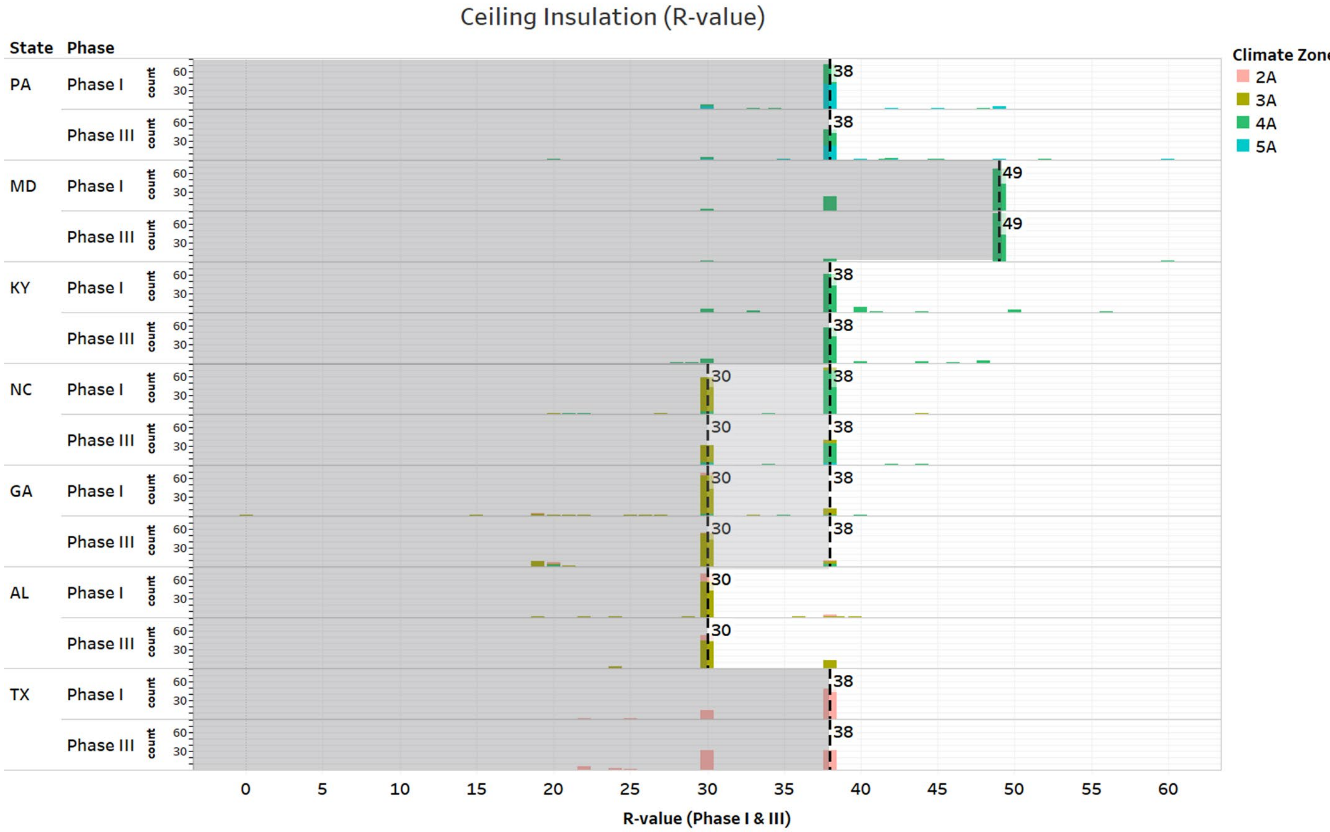

Figure 4.15. Ceiling Insulation R-values Phase I and Phase III Comparison

Table 4.6. Phase I and Phase III Ceiling Insulation R-values Compliance Rate

State	Code Requirement (R-value)	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Pennsylvania	38	80 of 89 (90%)	60 of 68 (88%)	-2%
Maryland	49	67 or 93 (72%)	79 of 84 (94%)	+22%
Kentucky	38	77 of 86 (90%)	69 of 78 (88%)	-2%
North Carolina	30 (CZ3) 38 (CZ4&5)	130 of 141 (92%)	70 of 75 (93%)	+1%
Georgia	30 (CZ2&3) 38 (CZ4)	83 of 99 (83%)	65 of 82 (79%)	-4%
Alabama	30	80 of 84 (95%)	66 of 69 (96%)	+1%
Texas	38	49 of 66 (74%)	31 of 72 (43%)	-31%

- **Interpretations**:
  - States demonstrated a relatively high compliance rate in Phase I and Phase III when compared to the prescriptive R-value.
  - Maryland saw the most significant improvement in compliance with a 22% change, while Texas saw a 31% drop in compliance from Phase I to Phase III. All other states largely maintained the same compliance level for both phases, hovering between 80–95%.

4.1.8 Ceiling IIQ

Figure 4.16 shows the ceiling insulation IIQ by state for Phases I and III.

	State / Phase													
	PA		MD		KY		NC		GA		AL		TX	
Ceiling Insulation (IIQ)	PI	PIII	PI	PIII	PI	PIII	PI	PIII	PI	PIII	PI	PIII	PI	PIII
I	53%	18%	92%	100%	40%	74%	71%	75%	19%	79%	73%	94%	73%	99%
II	45%	75%	8%		55%	26%	26%	19%	47%	21%	24%	6%	22%	1%
III	2%	7%			6%		4%	5%	34%		3%		4%	

Figure 4.16. Ceiling IIQ Phase I and Phase III

Although most states demonstrated high compliance with ceiling R-value, IIQ reduced the overall level of effectiveness, resulting in much lower U-factor compliance, which is discussed further in Section 4.1.9. However, many states made improvements in IIQ from Phase I to Phase III.

- **Interpretations**:
  - All states except Pennsylvania improved ceiling IIQ, with Georgia demonstrating the largest swing from Grade III to Grade I between phases.
  - Maryland, Alabama, and Texas had full or nearly full compliance with Grade I insulation in Phase III.

Ceiling IIQ saw a greater improvement than frame wall cavity IIQ. One reason for this is the level of effort to achieve Grade I for blown insulation is less than what is required in wall cavity insulation.

4.1.9 Ceiling Insulation (U-factor)

As shown in Figure 4.17, Figure 4.18, and Table 4.7 the significant level of non-compliance with IIQ had a considerable impact on the overall performance of the ceiling insulation assembly, which is especially present in Phase I. Ceiling insulation is an excellent example of why it is not just the amount of insulation that matters but also how accurately it is installed.

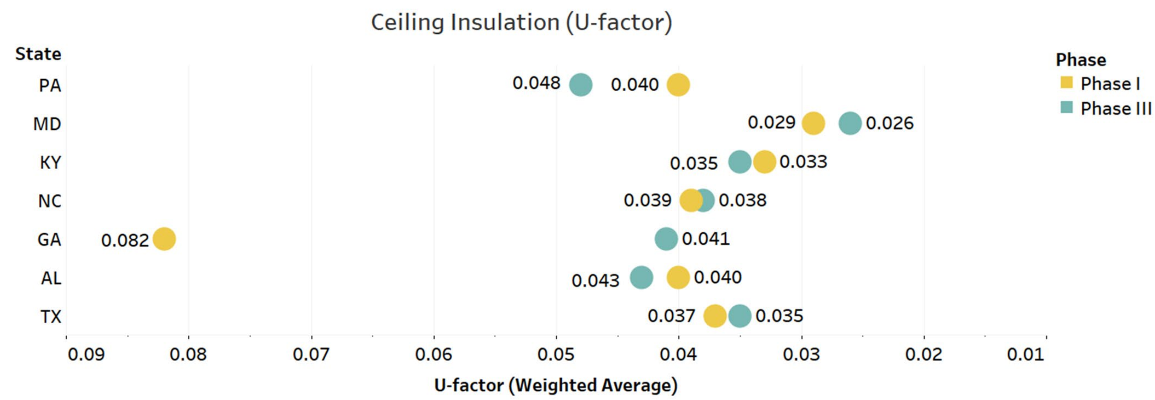

Figure 4.17. Average Ceiling Insulation U-factors Phase I and Phase III

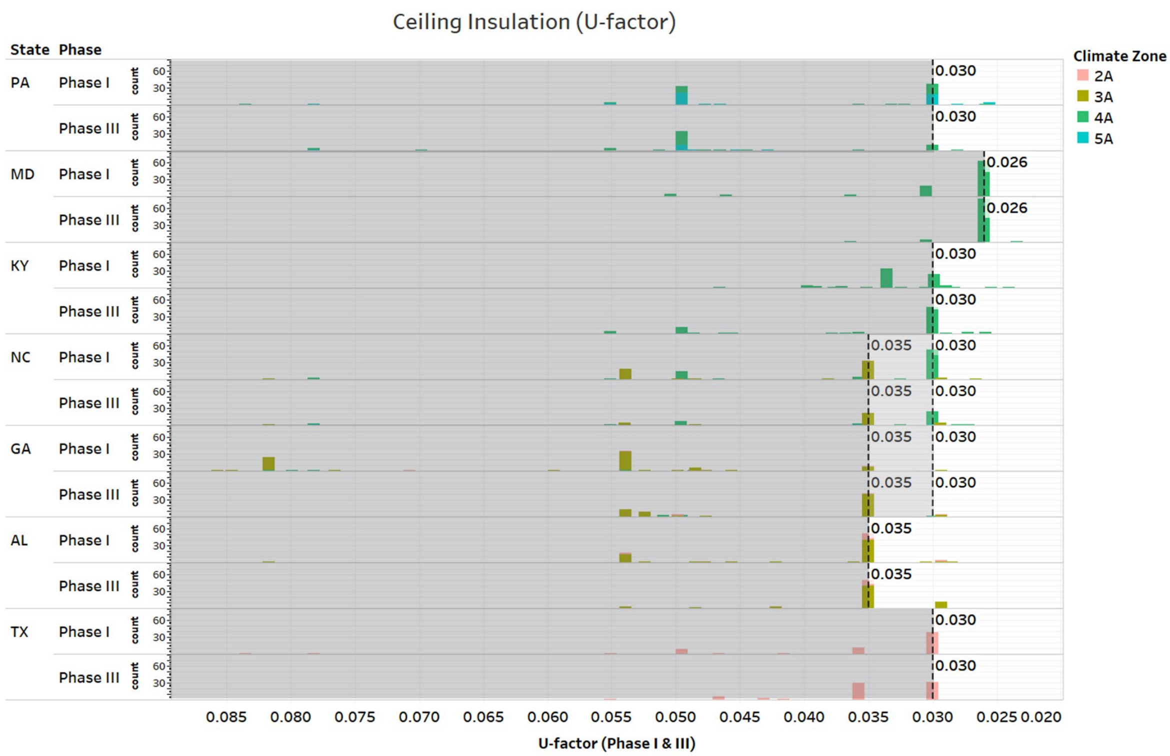

Figure 4.18. Ceiling Insulation U-factors Phase I and Phase III Comparison[24]

Table 4.7. Phase I and Phase III Ceiling Insulation U-factors Compliance Rate

State	Code Requirement (U-factor)	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Pennsylvania	0.030	44 of 89 (49%)	11 of 68 (16%)	-33%
Maryland	0.026	64 of 93 (69%)	79 of 84 (94%)	+25%

[24] Georgia had one Phase I observation at 0.111 that is not shown on this graph.

State	Code Requirement (U-factor)	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Kentucky	0.030	35 of 86 (41%)	55 of 78 (71%)	+30%
North Carolina	0.035 (CZ3) 0.030 (CZ4&5)	90 of 141 (64%)	53 of 75 (71%)	+7%
Georgia	0.035 (CZ2&3) 0.030 (CZ4)	11 of 99 (11%)	49 of 82 (60%)	+49%
Alabama	0.035	63 of 84 (75%)	61 of 69 (88%)	+13%
Texas	0.030	39 of 66 (59%)	31 of 72 (43%)	-16%

- **Interpretations**:
  - Compliance with R-value requirements ranged from 72-95% in Phase I, while U-factor compliance was much lower, ranging from 11-75%. Poor IIQ has a direct impact on the resultant ceiling assembly U-factor.
  - Focusing on IIQ in training demonstrated improvement in U-factor compliance in Phase III in all but two states, and significant improvement (25% or greater) in Maryland, Kentucky, and Georgia.

4.1.10 High-Efficacy Lighting

As shown in Figure 4.19, Figure 4.20, and Table 4.8, for high-efficacy lighting, all states improved in terms of weighted average, compliance distribution, and compliance rate from Phase I to Phase III.

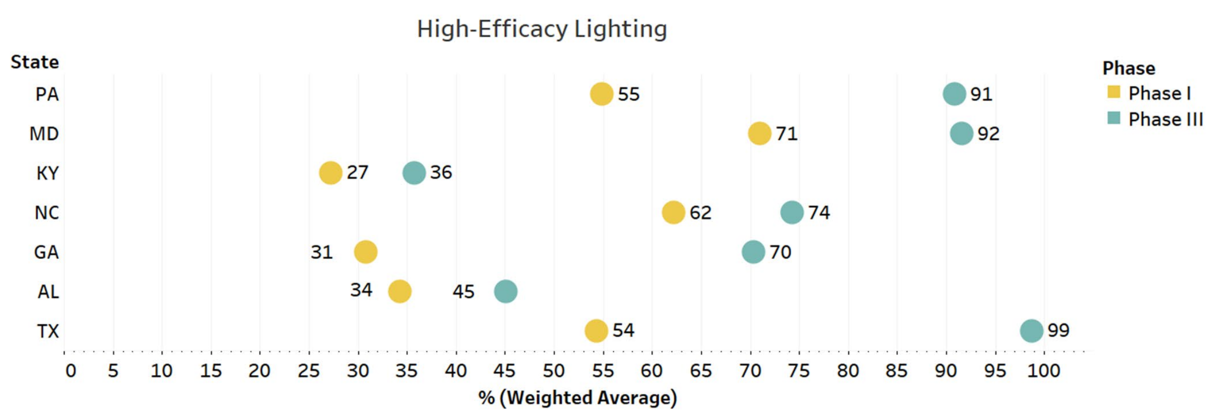

Figure 4.19. Average High-Efficacy Lighting % Phase I and Phase III

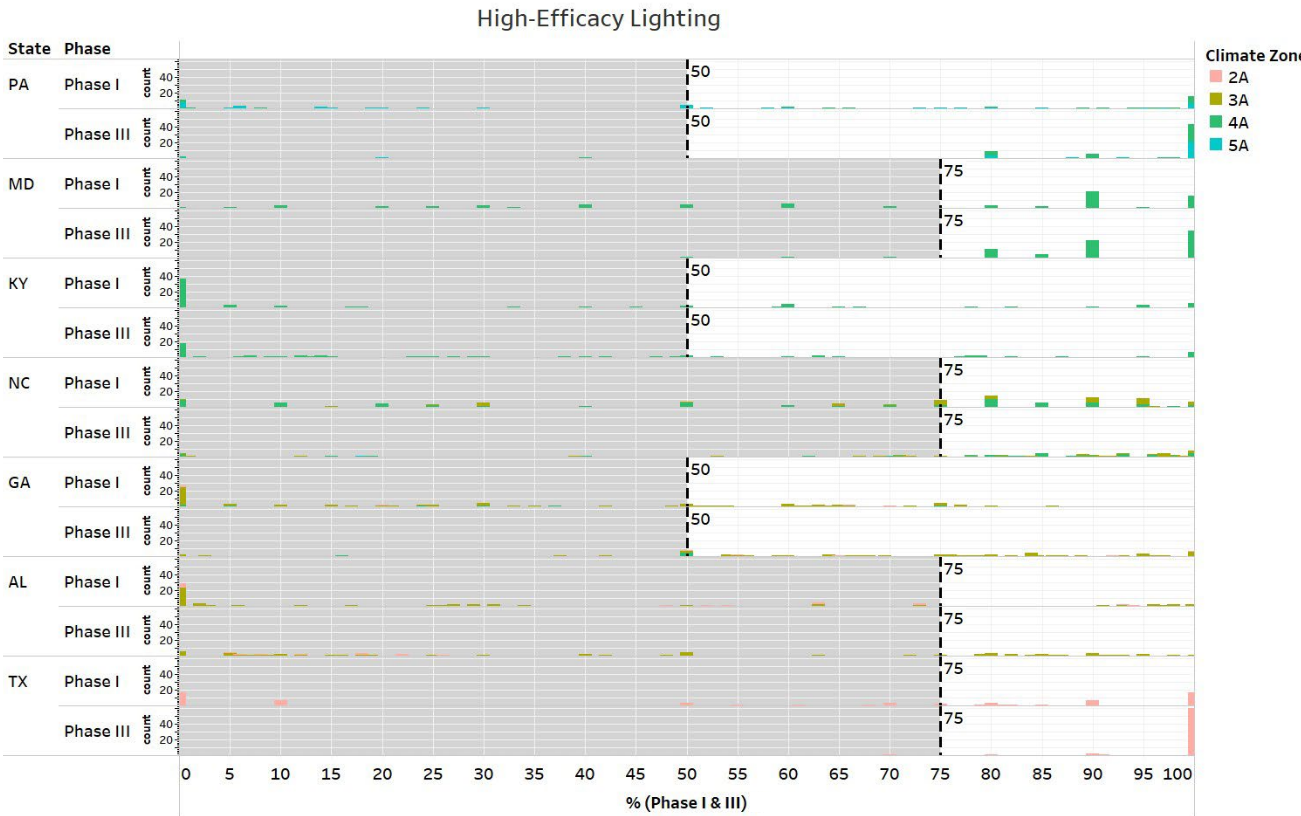

Figure 4.20. High-Efficacy Lighting % Phase I and Phase III Comparison

Table 4.8. Phase I and Phase III High-Efficacy Lighting % Compliance Rate

State	Code Requirement	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Pennsylvania	50%	39 of 63 (62%)	61 of 65 (94%)	+32%
Maryland	75%	43 of 71 (61%)	71 of 74 (96%)	+35%
Kentucky	50%	21 of 68 (31%)	22 of 63 (35%)	+4%
North Carolina	75%	60 of 106 (57%)	44 of 63 (70%)	+13%
Georgia	50%	29 of 79 (38%)	53 of 63 (84%)	+46%
Alabama	75%	15 of 71 (21%)	23 of 63 (37%)	+16%
Texas	75%	32 of 66 (48%)	64 of 65 (98%)	+50%

The key item with the most variability in observations is lighting, with numbers ranging from 0 to 100 as shown in Figure 4.20. The most common instances were often at the endpoints.

- **Interpretations**:
  - This is the only key observation where all states improved in terms of weighted average, compliance distribution, and compliance rate from Phase I to Phase III.
  - Pennsylvania, Maryland, and Texas were almost at full compliance in Phase III, with Texas showing a 50% improvement – the highest rate of change across all states.

– Kentucky showed a reduction in observations with 0% high-efficacy lamps and a 9% improvement on average but maintained a low compliance rate and little improvement from Phase I to Phase III. Alabama had a similar compliance rate to Kentucky in Phase III with 37% compliance, but the code requirement is 25% higher.

4.1.11 Window U-factor

Figure 4.21 shows the window U-factors for Phases I and III. As shown in Figure 4.22 and Table 4.9, the vast majority of window U-factor observations not only met but exceeded the code requirements in all locations.

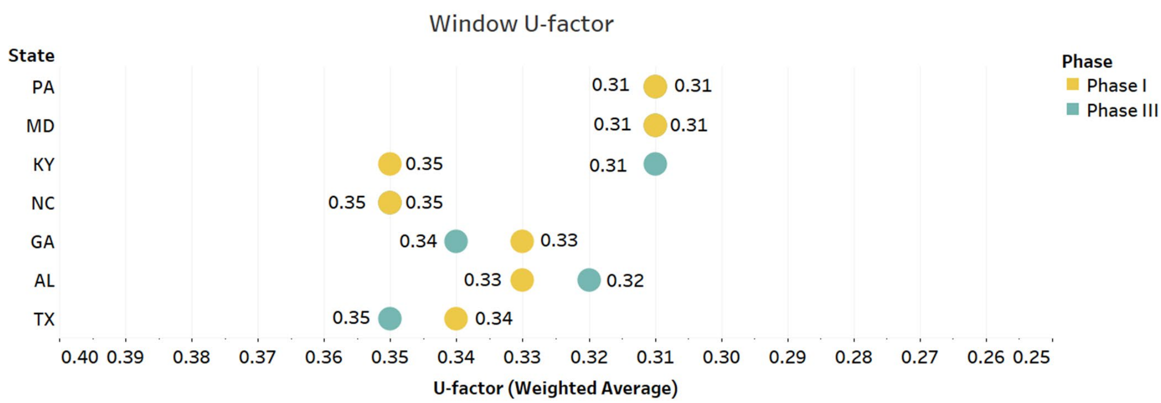

Figure 4.21. Average Window U-factors Phase I and Phase III[25]

[25] States with a single yellow dot indicate the average Window U-factor in Phase I and Phase III were roughly equivalent.

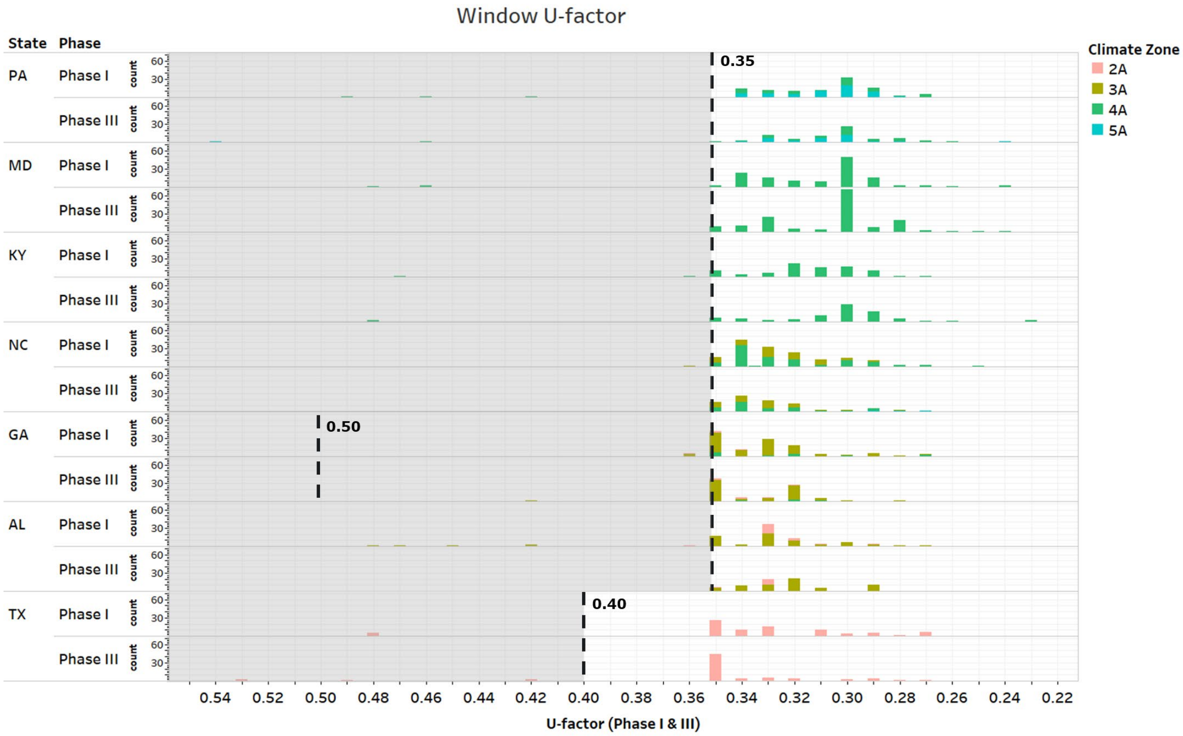

Figure 4.22. Window U-factors Phase I and Phase III Comparison

Table 4.9. Phase I and Phase III Window U-factors Compliance Rate

State	Code Requirement (U-factor)	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Pennsylvania	0.35	104 of 107 (97%)	72 of 74 (97%)	0%
Maryland	0.35	132 of 135 (98%)	155 of 155 (100%)	+2%
Kentucky	0.35	89 of 91 (98%)	82 of 85 (96%)	-2%
North Carolina	0.35	159 of 160 (99%)	86 of 86 (100%)	+1%
Georgia	0.5 (CZ2&3) 0.35 (CZ4)	122 of 122 (100%)	85 of 85 (100%)	0%
Alabama	0.35	86 of 92 (94%)	71 of 71 (100%)	+6%
Texas	0.40	79 of 84 (94%)	65 of 72 (90%)	-4%

- **Interpretations**:
  - With the exception of Kentucky, all states either stayed the same or slightly improved compliance rates from Phase I to Phase III.
  - All states with the exception of Texas were at or near full compliance in Phase III.

4.1.12 Window SHGC

Figure 4.23, Figure 4.24, Table 4.10 display window SHGC compliance. Similar to window U-factor, SHGC also had very high rates of compliance across states. As shown in Table 4.10, the three states in colder climates do not have an SHGC code requirement; therefore, for illustrative purposes, the compliance rate was set at 0.40 in Figure 4.24 for comparison to states with a requirement.

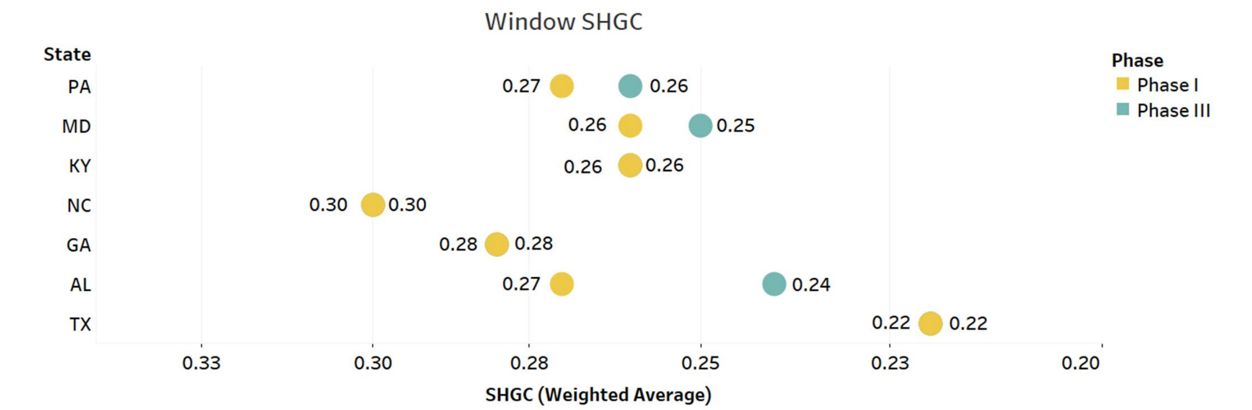

Figure 4.23. Average Window SHGC Phase I and Phase III

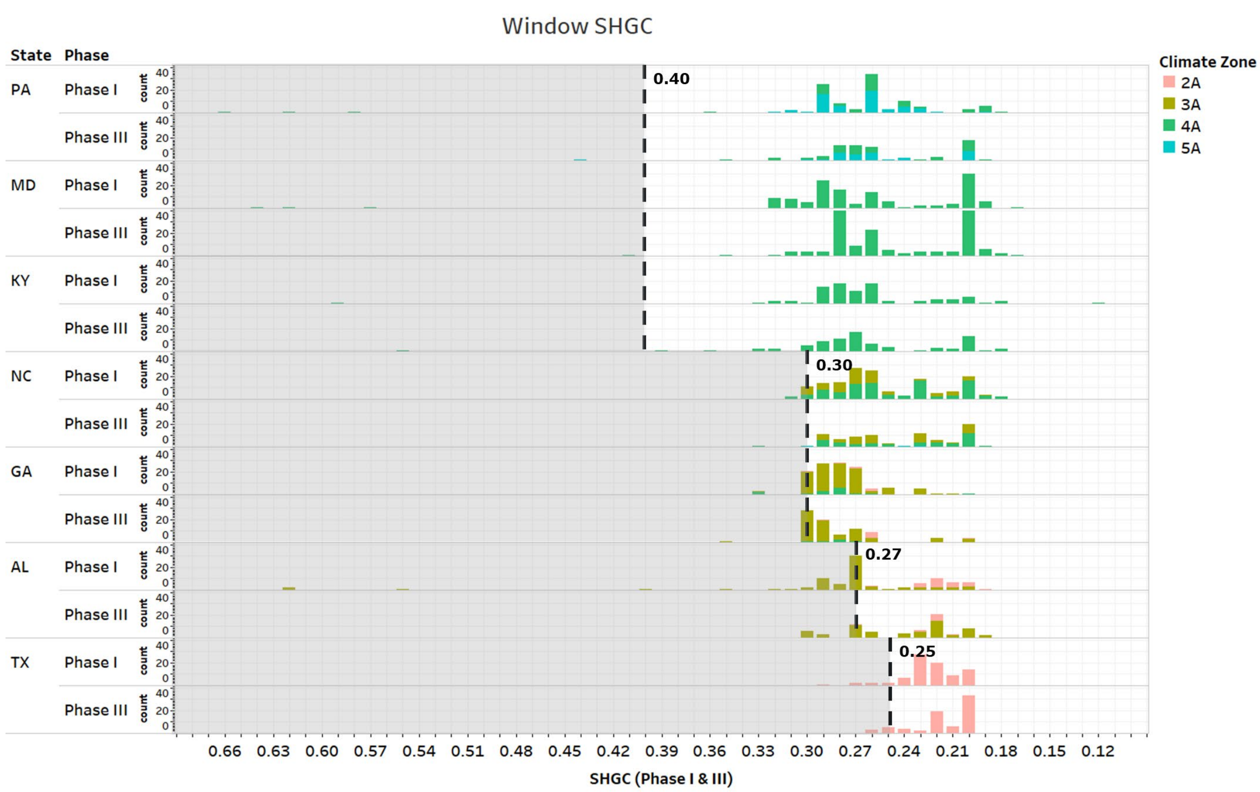

Figure 4.24. Window SHGC Phase I and Phase III Comparison

Table 4.10. Phase I and Phase III Window SHGC Compliance Rate

State	Code Requirement (SHGC)	Phase I (Compliance Rate)	Phase III (Compliance Rate)	Percent Change
Pennsylvania	0.4	-	-	-
Maryland	0.4	-	-	-

Kentucky	0.4	-	-	-
North Carolina	0.3	158 of 160 (99%)	85 of 86 (99%)	0%
Georgia	0.3	119 of 122 (98%)	84 of 85 (99%)	+1%
Alabama	0.27	68 of 92 (74%)	62 of 71 (87%)	+13%
Texas	0.25	79 of 84 (94%)	69 of 72 (96%)	+2%

- **Interpretations**:
  - Of the states with an SHGC code requirement, only Alabama had an opportunity to improve their compliance rate from Phase I to Phase III. They improved by 13%, bringing it up to 87% in Phase III.

4.1.13 Additional Analysis

In addition to collecting all key item data, the DOE methodology requires project teams to collect as much data as possible while on site. The additional data include assessing visual compliance with air sealing measures, mechanical ventilation type, HVAC equipment efficiency, duct and pipe insulation, and other factors. These additional measures provide an opportunity to compare to key measures and discover interesting trends. This section discusses some of the most prominent trends outside the scope of the initial study, but with robust data collection, these trends can be analyzed. The methodology employed to conduct the following sets of analyses is based on a previous report comparing 27 states that conducted a residential single-family field study (Reiner et al. 2020). See Appendix D for a complete comparison of additional data.

4.1.13.1 Envelope Tightness: Visual Inspection vs. Performance Test

The 2009 IECC provides the option of a visual inspection or envelope tightness test to assess compliance with the air sealing and insulation section of the code. In the 2012 IECC, visual inspections were removed as an optional compliance pathway, and a performance test is now required to determine compliance in all subsequent codes. Because three of the seven state codes within this study provide the visual inspection option, and data were collected on compliance with a visual inspection and performance test, an analysis was conducted to determine the efficacy of visual inspections as a mechanism to assure compliance.

Table 4.11 compares the overall compliance rate by using a visual inspection to a blower door test for various envelope tightness requirements as outlined in the state codes. To assess the visual inspection compliance rate, the number of compliant observations associated with Table R402.4.1.1 Air Barrier and Insulation Installation in the IECC was divided by the total number of observations for each category (ICC 2016). To assess the compliance rate of the performance test column, a similar ratio was created of the number of compliant envelope testing observations divided by the total number of observations tested with a blower door test.

Table 4.11. Envelope Tightness Visual Inspection vs. Blower Door Test

Code Requirement	Compliance Rate based on Visual Inspection	Compliance Rate based on Performance Test
All Homes (n=925)	78.5%	76.5%
≤7 ACH50 (n=403)	71.5%	90.3%

≤5 ACH50 (n=388)	72.9%	69.1%
≤3 ACH50 (n=134)	98.5%	56.7%

Table 4.11 demonstrates the important role of envelope tightness testing in the IECC, especially as the compliance target rate becomes more stringent. Interestingly, there is a nearly identical compliance rate when looking at all homes that were tested; however, the visual and tested compliance columns quickly diverge as the code requirement changes. There are several takeaways from this analysis, but the primary finding is that visual inspections cannot accurately determine compliance with the envelope tightness measure. This is apparent in states with a code requirement of 7 ACH50 with the visual inspection underrepresenting code compliance and in Maryland at 3 ACH50, where the visual approach vastly overrepresents compliance.[26]

4.1.14 Envelope Tightness and Ventilation Type

An important consideration for any builder is whether and what type of mechanical ventilation to install in a home. As specified in the 2012 and 2015 IECC editions, the building needs to be equipped with mechanical ventilation that meets the International Residential Code (IRC) or International Mechanical Code (IMC), which directly hinges on the tightness of the building envelope. As stated in Chapter 3 of the IRC, “where the air infiltration rate of a dwelling unit is 5 air changes per hour or less where tested with a blower door… in accordance with Section N1102.4.1.2, the dwelling unit shall be provided with whole-house mechanical ventilation” (ICC 2020). Understanding the relationship between envelope tightness and mechanical ventilation is critical to reducing building risks.

As demonstrated in the previous section, visual inspections are a poor indicator of understanding envelope tightness, and homes are tighter than builders think. The Kentucky study’s prime researcher analyzed this relationship, given that visual inspections are an optional compliance pathway in the state. Of the 23 homes that were confirmed to be verified with a visual inspection, “seventy-four percent of tested homes had a leakage rate of less than 5 ACH50, yet only one of the 23 homes (1.99 ACH50) had a fresh air system integrated into the air handling unit” (MEEA 2018). All other homes were noted to have bath fans installed.

A similar analysis has been expanded for the seven states within the study, as shown in **Figure 4.25** and **Figure 4.26**.

[26] A state specific analysis comparing envelope tightness compliance via a visual inspection and blower door test is in Appendix B.

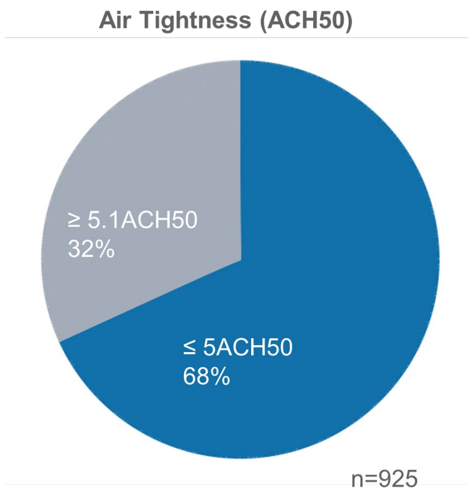

Figure 4.25. Breakdown of All Observations Above and Below 5 ACH50

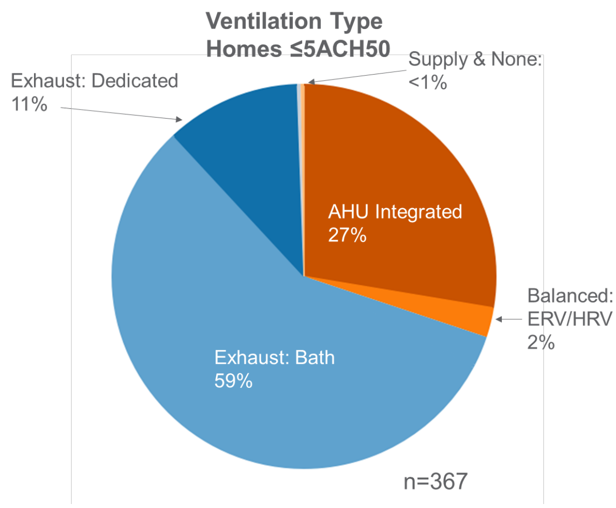

Figure 4.26. Comparison of Ventilation Type among Observations ≤5 ACH50

This expanded analysis considers the relationship between envelope tightness and the type of ventilation installed for all states. **Figure 4.25** demonstrates that 68% of all homes tested at a leakage rate of 5 ACH50 or less, which, as noted, is the threshold for when mechanical ventilation is required. For states with an envelope tightness requirement of 5 ACH50 or below, mechanical ventilation should be assured as long as the home meets the tightness requirement. However, as identified (MEEA 2018), builders in states without required testing do not know if they hit the 5 ACH50 threshold and thus need to mechanically ventilate. Regardless of the envelope tightness requirement, homes that tested at 5 ACH50 or below should have mechanical ventilation installed.

As displayed in **Figure 4.26**, of the homes that met the 5 ACH50 threshold, and for which ventilation type data were collected (n=366), there are some surprising findings. First, there are very few observations with a balanced ventilation system (2%). Dedicated exhaust systems represent the next largest percentage, likely indicating that an exhaust system other than a bathroom fan was installed. An air handling unit (AHU) integrated system is typically a form of supply-only ventilation connected to the return side of the air handler. Similar to what was reported in Kentucky, the most common type of mechanical ventilation system was a bathroom exhaust fan only (59%). Although a bathroom exhaust fan can meet the ventilation requirements of the IRC, these fans must have the proper controls and be installed appropriately for them to run continuously or intermittently to achieve the requisite cubic feet per minute. Unfortunately, this analysis leaves more questions than answers, as the ventilation rate was not collected as part of the study, making it impossible to know whether the bath fans were equipped to meet mechanical ventilation code requirements. Regardless, the low occurrence of balanced systems and high occurrence of bath fans as a means for mechanical ventilation raise some concerns and warrant further investigation.

4.1.15 Duct Leakage in Conditioned Space

As outlined in the IECC, all ductwork is to be sealed regardless of its location with respect to the building thermal envelope (i.e., inside and outside the conditioned envelope). However, as noted previously, duct tightness testing is only required on ductwork that is outside the conditioned space given the direct energy impacts from conditioned air leaking outside of the home. As required in the methodology, all ducts were tested, so a sample of homes with duct systems in 100% conditioned space was available for comparison to systems with ducts outside the conditioned space.

In Table 4.12, duct tightness observations were segmented by the level of code stringency, and then duct tightness was compared on systems with ducts in unconditioned space to those with 100% in conditioned space.

Table 4.12. Average Duct Tightness by Code Requirement: Unconditioned vs. Conditioned Space

Code Requirement (cfm25/100 ft^2)	Average Duct Tightness (Unconditioned Space)	Unconditioned Space Sample Size (n)	Average Duct Tightness (100% Conditioned Space)	100% Conditioned Space Sample Size (n)
4	5.8	409	4.5	60
12	13.1	337	22.4	74

Findings from this analysis provide some unexpected insights into the level of duct leakage across these system types. Based on these limited results, the implication is that for states with less stringent duct tightness requirements, like Kentucky, Georgia, and Pennsylvania, ducts are nearly twice as leaky when they are in 100% conditioned space than in unconditioned space. This trend intuitively makes sense given that ducts in conditioned space are not required to be tested and therefore may not be sealed to the level of rigor as other duct systems. However, this trend does not hold true in states with more stringent duct leakage requirements, and in fact, the opposite is true. Hypothesizing a reason for this finding is difficult with the limited data available, but this is a primary area for additional research as more state single-family code baseline studies are conducted.[27]

Leaky ductwork, regardless of whether it is in conditioned or unconditioned space, reduces the ability to effectively move conditioned air to all supply registers in a home, thereby impacting occupant comfort. The 2021 IECC addresses this issue by requiring all ducts, regardless of location, to be pressure tested and achieve a minimum tightness rate. Ducts within conditioned space must limit leakage to ≤ 8 cfm25/100 ft^2, while ducts outside conditioned space must achieve ≤ 4 cfm25/100 ft^2.

4.2 Comparison of Baseline and Observed EUIs in Phase I and Phase III

The initial DOE field study methodology was designed to detect a statistically significant difference in estimated statewide energy use between Phases I and III, with a state-level sensitivity corresponding to an EUI of 1.25 kBtu/ft^2 among all states except Pennsylvania. [28] Meaning, any change above that threshold would indicate that a statistically significant change had taken place. Table 4.13 shows the mean prescriptive, Phase I, and Phase III EUIs for the seven states that completed both pre-and post-studies. In the Delta columns, a negative number indicates less energy was used as compared to the prescriptive EUI (code baseline) or Phase I, where a positive number means more energy use on average.

[27] A state-specific analysis comparing duct tightness between unconditioned and conditioned systems is in Appendix A.
[28] The 1.25 kBtu/ft^2 metric is not applicable to PA per the DOE Methodology. The threshold for statistical significance in Pennsylvania is 2.35 kBtu/ft^2.

Table 4.13. Change in Average Statewide Energy Use by State

State	Prescriptive EUI [(a)]	Phase I EUI	Phase I vs. Prescriptive Delta	Phase III EUI	Phase III vs. Prescriptive Delta	Phase III vs. I Delta
PA	45.48	40.73	-4.75	43.70	-1.78	2.97
MD	27.56	30.49	2.93	27.51	-0.05	-2.98
KY	33.98	31.31	-2.67	29.49	-4.49	-1.82
NC	23.79	22.96	-0.83	23.26	-0.53	0.30
GA	28.52	26.52	-2.00	24.48	-4.04	-2.04
AL	18.41	19.81	1.40	19.04	0.63	-0.77
TX	22.15	22.57	0.42	20.74	-1.41	-1.83

(a) Calculated based on the minimum prescriptive requirements of the state energy code.

Using the metric above to indicate a statistically significant change occurred, four of the seven states met this threshold with a range of changes in average EUI from -1.82 in Kentucky to -2.98 in Maryland, representing a reduction in overall energy use from 6 to 10% from Phase I to Phase III. The average observed EUI in Alabama decreased by 0.77 kBtu/ft^2, a decrease in energy use of approximately 3.9%. However, because this differential is below the threshold established under the study methodology, the results cannot be considered statistically conclusive. Two states, North Carolina and Pennsylvania, had an increase in the average observed EUI from Phase I to Phase III, meaning that the average energy use increased from Phase I to Phase III.

When comparing Phase III results to statewide prescriptive EUIs, a slightly different story emerges. Kentucky, Georgia, and Texas all demonstrate a statistical improvement, while Maryland does not quite rise to the level of improvement over the state prescriptive EUI. One potential reason for this is that Maryland had the most stringent energy code of all states, which went into effect right before Phase I started. However, the improvement Maryland displayed from Phase I to Phase III was significant. All other states, except Alabama, had a lower Phase III EUI than the prescriptive, but again, did not meet the threshold for statistical significance. A key takeaway is, on an average EUI basis, in Phase III, all states were on par or slightly better than the state prescriptive EUI, but as demonstrated in the field observation analysis, significant savings opportunities still exist.

The distribution of observed EUI for the complete datasets in Phase I and Phase III in each state is displayed in Figure 4.27. This graph is configured to show that any EUI to the left of the vertical line for each state is higher than the prescriptive code EUI, or compliance baseline. As observed in the EUI comparison graph, states where the EUI improved have a greater distribution of observations to the right side of the compliance line, which was true for most states.

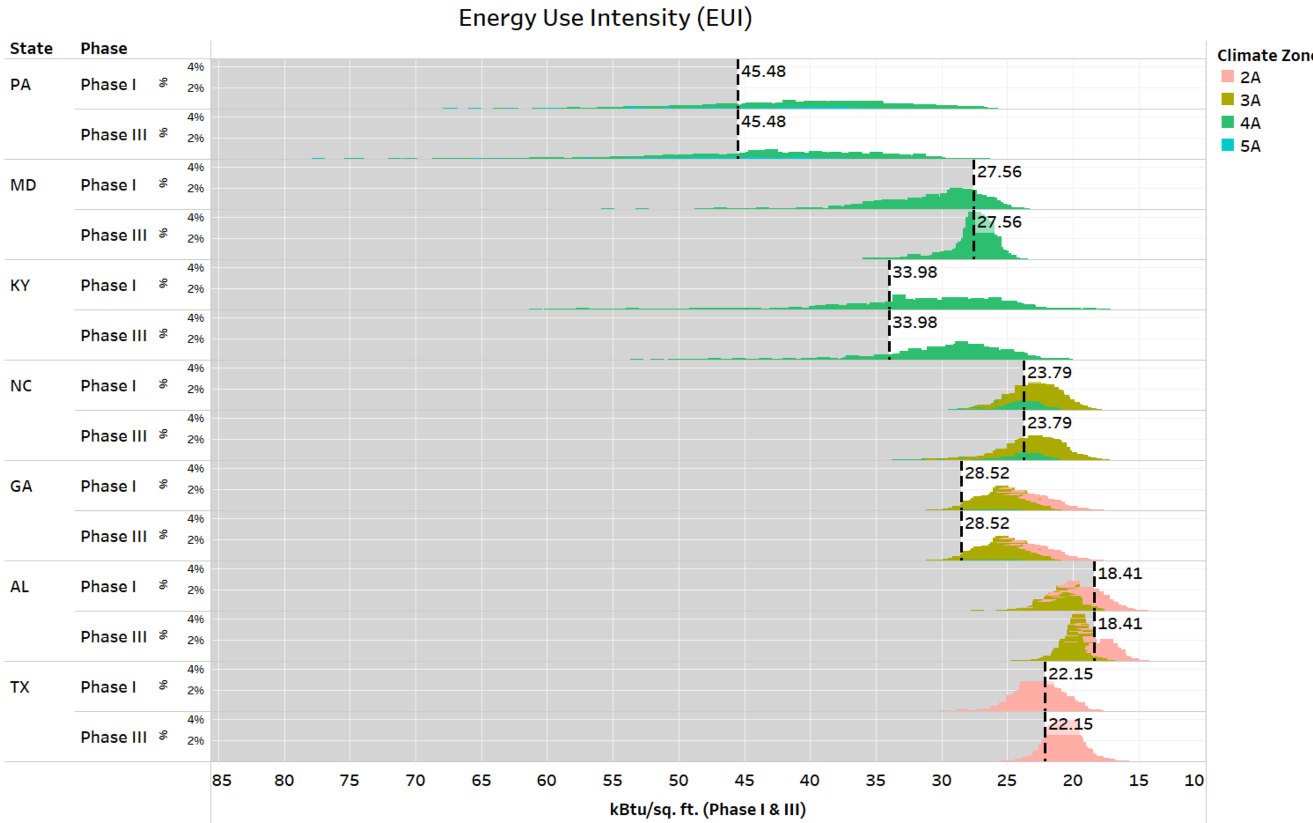

Figure 4.27. Comparison of Phase I and Phase III Statewide EUIs

4.3 Comparison of Measure Level Savings in Phase I and Phase III

In terms of savings potential associated with individual measures, most key items exhibit improvement, but not in all cases. Table 4.14 presents the difference in annual savings between Phase I and Phase III. States and measures associated with a green cell and positive number indicate improved compliance, which generated energy cost savings. Conversely, red cells with numbers in parentheses indicate that the compliance rate decreased for that particular measure, resulting in an increase in potential energy savings from Phase I to Phase III. Table 4.15 displays the Phase I and Phase III annual estimated potential energy cost savings and the respective percent change for each measure and state. The DOE methodology targeted any key item where at least 15% of field observations did not meet the corresponding prescriptive code requirement. Potential energy savings in the following tables were based on this 15% threshold.

Table 4.14. Measure-level Annual Estimated Savings Potential Difference (Phase III vs. I)

	State						
	PA	MD	KY	NC	GA	AL	TX
Envelope Tightness		$560,047	$473,993	($350,593)		$78,005	$484,152
Duct Tightness	$199,710	$122,024	($299,075)	($342,700)	$470,378	$71,825	$1,744,696
Wall Insulation	($105,642)	$327,981	$19,070	$64,372	$214,435	$26,025	$152,662
Ceiling Insulation	($393,994)	$34,059	$123,870	$68,075	$1,385,758		($324,033)
High-Efficacy Lighting	$324,076	$187,263	$44,161	$222,205	$694,964	$94,802	$1,546,362
Foundation Insulation	$161,199		($70,749)	($3,445)			
Window SHGC						$50,140	
Total Savings	$185,349	$1,231,374	$291,270	($342,086)	$2,765,535	$320,797	$3,603,839

Table 4.15. Measure-level Phase I and Phase III Annual Savings Potential (% Change)

State	Phase	Measure							
		Envelope Tightness	Duct Tightness	Wall Insulation	Ceiling Insulation	High-Efficacy Lighting	Foundation Insulation	Window SHGC	Total
PA	Phase I	NA	$1,360,493	$798,031	$499,392	$365,254	$175,676	NA	$3,198,846
	Phase III	NA	$1,160,783	$903,673	$893,386	$41,178	$14,477	NA	$3,013,497
	% Change	NA	14.7%	-13.2%	-78.9%	88.7%	91.8%	NA	5.8%
MD	Phase I	$754,946	$146,619	$401,479	$44,366	$195,378	NA	NA	$1,542,788
	Phase III	$194,899	$24,595	$73,498	$10,307	$8,115	NA	NA	$311,414
	% Change	74.2%	83.2%	81.7%	76.8%	95.8%	NA	NA	79.8%
KY	Phase I	$484,314	$43,142	$171,044	$215,656	$197,544	$108,156	NA	$1,219,856
	Phase III	$10,321	$342,217	$151,974	$91,786	$153,383	$178,905	NA	$928,586
	% Change	97.9%	-693.2%	11.1%	57.4%	22.4%	-65.4%	NA	23.9%
NC	Phase I	$211,315	$334,527	$390,827	$503,364	$520,839	$65,086	NA	$2,025,958
	Phase III	$561,908	$677,227	$326,455	$435,289	$298,634	$68,531	NA	$2,368,044
	% Change	-165.9%	-102.4%	16.5%	13.5%	42.7%	-5.3%	NA	-16.9%
GA	Phase I	NA	$685,683	$1,151,262	$1,880,668	$799,065	NA	NA	$4,516,678
	Phase III	NA	$215,305	$936,827	$494,910	$104,101	NA	NA	$1,751,143
	% Change	NA	68.6%	18.6%	73.7%	87.0%	NA	NA	61.2%
AL	Phase I	$263,089	$395,063	$201,105	NA	$385,451	NA	$54,674	$1,299,382
	Phase III	$185,084	$323,238	$175,080	NA	$290,649	NA	$4,534	$978,585
	% Change	29.6%	18.2%	12.9%	NA	24.6%	NA	91.7%	24.7%
TX	Phase I	$654,623	$1,914,867	$511,748	$216,147	$1,550,412	NA	NA	$4,847,797
	Phase III	$170,471	$170,171	$359,086	$540,180	$4,050	NA	NA	$1,243,958
	% Change	74.0%	91.1%	29.8%	-149.9%	99.7%	NA	NA	74.3%

The largest improvements reported in terms of total savings are duct tightness and high-efficacy lighting in Texas (CZ 2A), an increase in compliance that equates to over $1.7 million (a 91.1% change), and over $1.5 million (99.7%), respectively. Other measures with significant savings as a result of increased compliance include ceiling insulation in Georgia at nearly $1.4 million (73.7%), envelope tightness in Maryland at over $500,000 (74.2%) and Kentucky at nearly $500,000 (97.9%), and high-efficacy lighting in Pennsylvania at over $300,000 (88.7%). However, other measures in certain states did not improve, such as duct tightness in Kentucky and North Carolina and ceiling insulation in Pennsylvania and Texas. Maryland, Georgia, and Alabama improved across all measures with potential energy savings in Phase I, albeit the improvement level is significantly smaller in Alabama. High-efficacy lighting is the only measure with potential savings across all states in Phase I that also demonstrated improvement across states in Phase III.

However, given that these saving numbers are on a climate zone (TX) or statewide basis, and the number of homes constructed in each state varies significantly, this does not provide for an equal comparison across states.

Figure 4.28 provides a graphical representation of measure level savings from Phase I to Phase III across all states per 1,000 new homes (Reiner et al. 2020). This enables an equal comparison across measures and states to accurately assess each measure's level of impact. Each measure represents a different color in the graph. Any measure above $0 on the y-axis indicates the difference between Phase I and III is positive, while measures below that axis demonstrate a negative result (no improvement).

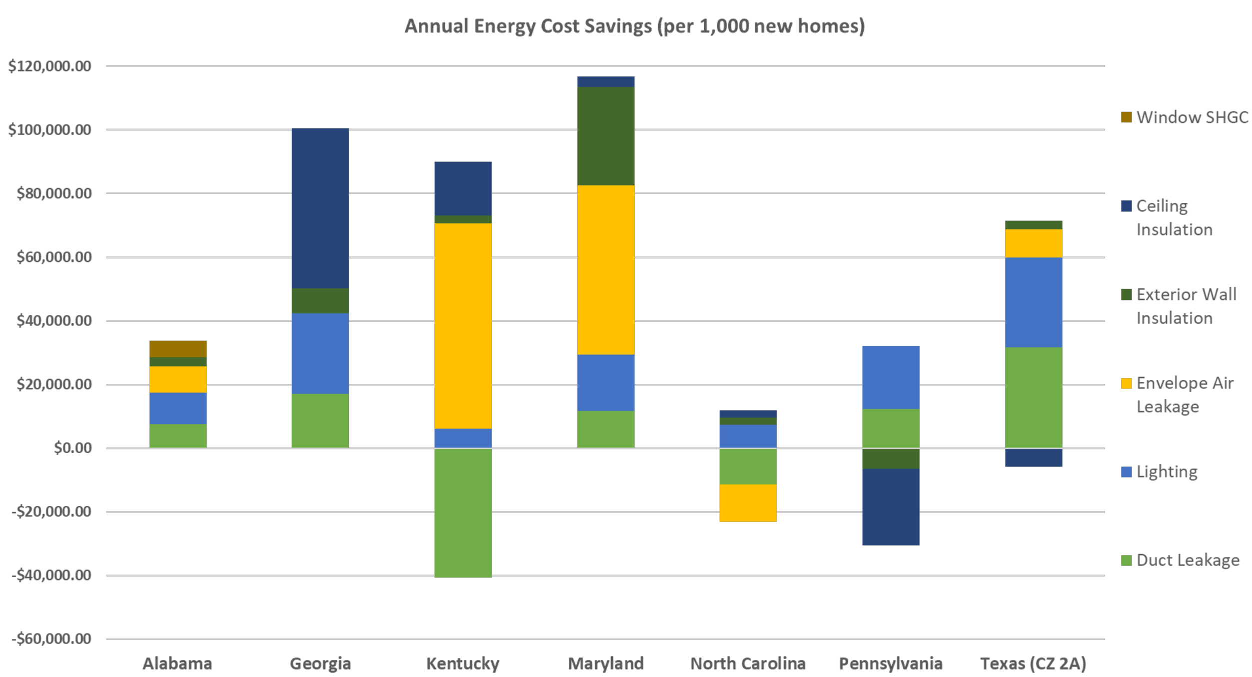

Figure 4.28. Measure-level Annual Energy Cost Savings per 1,000 New Homes (Phase I to Phase III)

Key takeaways from this graph are the following:

- Kentucky and Maryland saw the majority of savings from improved envelope tightness.
- Ceiling insulation was the biggest driver of savings in Georgia, followed by high-efficacy lighting.

- Lighting and duct leakage had the most savings in Texas and Pennsylvania, but other measures in Pennsylvania did not improve, resulting in a mixed outcome.

Table 4.16 drills down even further at the state comparison by displaying the potential energy savings on a per home basis across states. The change from Phase I to Phase III was positive in all states except North Carolina. Savings ranged from $12–$117 per home, an improvement of 5.8% in Pennsylvania to nearly 80% in Maryland.

Table 4.16. Total Annual Potential Energy Savings Per Home (Phase I to Phase III)

State	Phase I Annual Potential Savings (per home)	Phase III Annual Potential Savings (per home)	$ Change (per home)	% Change
PA	$217.95	$205.32	$12.63	5.8%
MD	$146.36	$29.54	$116.82	79.8%
KY	$166.08	$126.42	$39.66	23.9%
NC	$67.47	$78.86	-$11.39	-16.9%
GA	$164.22	$63.67	$100.55	61.2%
AL	$136.69	$102.94	$33.75	24.7%
TX	$88.24	$22.64	$65.60	74.3%

As outlined in this section, the impact of Phase II (training and education) varied across states and individual measures. As displayed in this high-level recap in Table 4.17, high-efficacy lighting improved 100% of the time, followed by wall insulation (86%), envelope tightness (80%), ceiling insulation (75%), and duct tightness (71%).[29] The consistent measure level improvement and significant estimated energy and cost savings across all states from Phase I to Phase III only underscore the critical role of education and training in implementing energy codes across states.

[29] Foundation insulation and window SHGC are excluded from this list given that they are only applicable to a select number of states.

Table 4.17. State and Measure Level Phase III Improvement

State	Envelope Tightness	Duct Tightness	Wall Insulation	Ceiling Insulation	Lighting
PA	NA	Yes	No	NA	Yes
MD	Yes	Yes	Yes	Yes	Yes
KY	Yes	No	Yes	Yes	Yes
NC	No	No	Yes	Yes	Yes
GA	NA	Yes	Yes	Yes	Yes
AL	Yes	Yes	Yes	NA	Yes
TX	Yes	Yes	Yes	No	Yes
% States Where Measures Improved	4 of 5 (80%)	5 of 7 (71%)	6 of 7 (86%)	4 of 5 (80%)	7 of 7 (100%)

4.4 Cumulative Estimated Savings Potential

Extrapolating Phase I and Phase III estimated potential savings per state over 5, 10, and 30 years highlights the enormous impact of regular energy code training and education programs. The savings here are larger than the simple sum of annual savings because savings from homes in year one continue to accrue annually and the savings for the new homes are added on to it. After 5 years, for example, there are 5 years' worth of savings from houses built in the first year, 4 years of savings from houses built in the second year, etc. If the Phase II program's effect continued year after year in these states, the potential impact after 30 years would be vast. As displayed in Table 4.18, the 30-year implications from a program like this could result in estimated potential savings of over 142 million MMBtu, \$3.7 billion, and a reduction of over 111 MMT CO2e.[30]

Table 4.18. Comparison of Phase I and Phase III Estimated Annual Savings Potential

Metric	Years	Phase I	Phase III	Difference
Total Energy Savings (MMBtu)	5	12,847,560	8,253,015	4,594,545
	10	47,107,720	30,261,055	16,846,665
	30	398,274,360	255,843,465	142,430,895
Energy Cost Savings (\$)	5	\$279,769,575	\$158,928,405	\$120,841,170
	10	\$1,025,821,775	\$582,737,485	\$443,084,290
	30	\$8,672,856,825	\$4,926,780,555	\$3,746,076,270
Total Emissions Reduction (MT CO2e)	5	6,717,060	3,132,825	3,584,235
	10	24,629,220	11,487,025	13,142,195

[30] The multi-year savings reflect the same reductions and increases as the annual savings and are simply the annual savings multiplied by 15, 55, and 465 for 5-year, 10-year, and 30-year savings, respectively. For analytical details refer to the methodology report (DOE 2018).

Metric	Years	Phase I	Phase III	Difference
	30	208,228,860	97,117,575	111,111,285

Table 4.19, Table 4.20, and Table 4.21 show the estimated energy, energy cost, and emission reduction savings potential for 5, 10, and 30 years across all states.

Table 4.19. Comparison of Phase I and Phase III 5-year, 10-year, and 30-year Cumulative Estimated Energy Savings Potential

State	Potential Total Energy Savings (MMBtu) 5 yr		Potential Total Energy Savings (MMBtu)10 yr		Potential Total Energy Savings (MMBtu) 30 yr	
	Phase I	Phase III	Phase I	Phase III	Phase I	Phase III
PA	2,933,445	2,930,055	10,755,965	10,743,535	90,936,795	90,831,705
MD	1,400,115	308,895	5,133,755	1,132,615	43,403,565	9,575,745
KY	937,620	704,100	3,437,940	2,581,700	29,066,220	21,827,100
NC	1,363,155	1,720,260	4,998,235	6,307,620	42,257,805	53,328,060
GA	2,419,500	1,095,360	8,871,500	4,016,320	75,004,500	33,956,160
AL	687,735	524,265	2,521,695	1,922,305	21,319,785	16,252,215
TX	3,105,990	970,080	11,388,630	3,556,960	96,285,690	30,072,480
Total	12,847,560	8,253,015	47,107,720	30,261,055	398,274,360	255,843,465

Table 4.20. Comparison of Phase I and Phase III 5-year, 10-year, and 30-year Cumulative Estimated Energy Cost Savings Potential

State	Potential Total Energy Cost Savings ($) 5 yr		Potential Total Energy Cost Savings ($) 10 yr		Potential Total Energy Cost Savings ($) 30 yr	
	Phase I	Phase III	Phase I	Phase III	Phase I	Phase III
PA	$47,982,690	$45,202,455	$175,936,530	$165,742,335	$1,487,463,390	$1,401,276,105
MD	$23,141,820	$4,671,210	$84,853,340	$17,127,770	$717,396,420	$144,807,510
KY	$18,297,840	$13,928,790	$67,092,080	$51,072,230	$567,233,040	$431,792,490
NC	$30,389,370	$35,520,660	$111,427,690	$130,242,420	$942,070,470	$1,101,140,460
GA	$67,750,170	$26,267,145	$248,417,290	$96,312,865	$2,100,255,270	$814,281,495
AL	$19,490,730	$14,678,775	$71,466,010	$53,822,175	$604,212,630	$455,042,025
TX	$72,716,955	$18,659,370	$266,628,835	$68,417,690	$2,254,225,605	$578,440,470
Total	$279,769,575	$158,928,405	$1,025,821,775	$582,737,485	$8,672,856,825	$4,926,780,555

Table 4.21. Comparison of Phase I and Phase III 5-year, 10-year, and 30-year Cumulative Estimated Emissions Reduction Potential

State	Potential Total Emissions Reduction (MT CO2e) 5 yr		Potential Total Emissions Reduction (MT CO2e) 10 yr		Potential Total Emissions Reduction (MT CO2e) 30 yr	
	Phase I	Phase III	Phase I	Phase III	Phase I	Phase III
PA	727,875	591,105	2,668,875	2,167,385	22,564,125	18,324,255

State	Potential Total Emissions Reduction (MT CO2e) 5 yr		Potential Total Emissions Reduction (MT CO2e) 10 yr		Potential Total Emissions Reduction (MT CO2e) 30 yr	
	Phase I	Phase III	Phase I	Phase III	Phase I	Phase III
MD	112,035	21,660	410,795	79,420	3,473,085	671,460
KY	114,795	91,380	420,915	335,060	3,558,645	2,832,780
NC	1,104,075	1,180,995	4,048,275	4,330,315	34,226,325	36,610,845
GA	1,829,040	589,680	6,706,480	2,162,160	56,700,240	18,280,080
AL	113,535	89,295	416,295	327,415	3,519,585	2,768,145
TX	2,715,705	568,710	9,957,585	2,085,270	84,186,855	17,630,010
Total	6,717,060	3,132,825	24,629,220	11,487,025	208,228,860	97,117,575

5.0 Conclusions

The first goal of the project, to develop a standardized methodology for assessing the energy impacts of code compliance, was successfully achieved. Over a dozen states have subsequently adopted the methodology to conduct their own independent energy code compliance field studies. Altogether, the studies have already helped inform further building energy code research and investments, shedding light on standard construction practices in single-family homes and the real-world performance of energy codes.

The second goal - testing whether statewide energy savings can be improved through education, training, and outreach activities - was demonstrated across nearly all states. In four of the seven states, a statistically significant improvement occurred in overall estimated average statewide energy consumption (i.e., based on the energy, or EUI, metric) ranging from 1.82 in Kentucky to 2.98 in Maryland, representing a 6–10% reduction in overall energy use from Phase I to Phase III.[31] When compared to the state prescriptive EUI in Phase III, statewide average EUIs were either on par or showed an overall reduction in energy use, albeit only three states demonstrated a statistically significant level of improvement.

At a measure level, compliance generally improved from Phase I to Phase III. Certain measures, such as requirements related to windows, consistently had high compliance rates, likely demonstrating the positive influence of broader market forces. Other measures demonstrate less consistent results and should remain focal points for future education and training programs. Lighting showed a consistent level of improvement across all states, resulting in a compliance improvement from 4 to 50% and a total estimated annual measure level savings of over $3.1 million, the largest total savings of any measure. Above-grade wall insulation also demonstrated consistent improvement, with all but one state improving. This was largely due to better IIQ, which was also a key reason for the improvement in ceiling insulation in all but two states. However, considerable savings opportunities persist with these measures, especially above-grade wall insulation, where compliance rates ranged from 16–68% in Phase III.

Lastly, most states saw an improvement in compliance of performance-based code requirements, notably envelope and duct tightness. Despite the fact that testing of the envelope was not required per code in three states, statewide averages ranged from 3 to 5 ACH50, which far exceeds the tightness threshold in these states. Combined, envelope and duct tightness improvement from Phase I to Phase III resulted in over $3.2 million in estimated annual cost savings potential.

Improved compliance in Phase III resulted in an annual estimated energy cost savings of over $8 million annually across all states, indicating a successful education and training program. Despite this success, more work can be done, as collectively, $10.6 million in estimated annual cost savings potential remains after Phase III that can be captured through improved compliance. Overall, these findings are encouraging and point to the successful implementation of Phase II, the education and training program. However, assessing the level of attribution from Phase II is outside the FOA scope and this report, so continued research and analysis is needed.

Moving forward, DOE encourages additional states, and states that have already conducted a study, to undertake similar studies every 3 to 5 years. DOE will continue to provide technical assistance to assist

[31] As noted earlier, Alabama does not meet the statistical sensitivity threshold defined under the study methodology; therefore, the results cannot be considered conclusive.

with study design, technical analysis, and administration of the resulting public data set.[32] More information on this assistance, as well as all current findings and supporting documentation, is available at energycodes.gov.[33]

[32] Data from the field studies referenced in this report as well as additional single family, multifamily, and commercial field studies are available for download at https://www.energycodes.gov/compliance/energy-code-field-studies.

[33] Additional information is available at https://www.energycodes.gov/compliance/energy-code-field-studies.

6.0 Future Research Opportunities

Through this pilot study the US DOE Building Energy Codes Program established a consistent and replicable methodology to assess statewide energy code compliance and demonstrate the economic and environmental benefits associated with improved rates of compliance. Since this pilot study was conducted, the energy code field study concept was expanded to assess low-rise multifamily[34] and simple commercial buildings,[35] and recently, under the Advanced Building Construction Initiative, pilots are underway in the high-rise off-site multifamily[36] and large complex commercial building[37] sectors. These new research opportunities were derived from this pilot, and many other ideas specific to the residential single-family sector have been considered in the years during and after the study. The authors of this report developed a short list of the more promising opportunities to continue advancing this methodological approach and resulting body of research.

- **Expanded Set of Measures:** Although each project team had the opportunity to add measures to the data collection form to be collected during the study, few teams did. While in the field, collecting data on measures related to emerging technologies (e.g., electric vehicle infrastructure), building resilience (e.g., backup batteries or generators), future code requirements (e.g., mechanical ventilation testing), among others can provide valuable information at a negligible additional cost. In particular, data can be used to inform future code development, resilience planning, utility programs and other programs and policies.

- **Assessing Compliance Equity:** As this pilot demonstrated, energy codes are not implemented universally from state to state. Differences in climate zones, energy codes, construction practices and many other state-specific distinctions likely lead to these findings. Given that statistical significance is at the state level for each pilot state, findings from this research cannot reveal differences in compliance within each state, such as at the county or city level. However, a key question for many states is whether residents are benefiting from a statewide energy code equally. Through additional sampling, project teams could collect subsets of data (63 samples for each subset) enabling statistically significant comparisons between urban and rural areas, high and low energy burdened census tracts, and expensive and modestly priced homes. Results from this type of study could help states prioritize the limited education and training resources to areas most in need.

- **Stretch Code Assessment:** The methodology developed through this pilot is flexible enough to analyze any set of code requirements, including stretch energy codes. Stretch codes are designed to enable jurisdictions within a state the ability to adopt a set of code requirements that are more advanced than the state base code, often reflecting what the state base code could be in the next few code cycles. Considering stretch codes can reflect the future base code, it may be beneficial to conduct a field study in jurisdictions that have adopted the stretch code so states can get an early indication of compliance challenges with a future base code. In particular, jurisdictions with electrification-only requirements may provide a timely set of compliance trends to other jurisdictions considering or in the process of decarbonizing their energy code.

[34] https://www.energycodes.gov/sites/default/files/2021-07/LRMF_Studies_final_report_2020-06-24.pdf
[35] https://www.energycodes.gov/commercial-energy-code-field-study
[36] https://www.energy.gov/eere/buildings/articles/modular-construction-energy-efficiency-field-study-commercial-and
[37] https://www.energy.gov/eere/buildings/articles/commercial-energy-efficiency-field-study-large-complex-buildings

- **Use of REScheck™ and Performance Reporting:** Data derived from the UA alternative (e.g., REScheck) and the performance compliance paths (R405 and R406) could help supplement field collected data, thereby reducing the cost and length of these studies. However, a robust, national study would be required to be conducted to validate that measure level data described in the compliance reports is consistent to what is found in the field. Conducting this type of study would provide data on the level of deviation found overall and at the measure level between compliance reports and constructed homes. Depending on findings, this methodology could be streamlined, and data regularly collected through DOE's REScheck™ and energy modeling software could be better utilized to understand code compliance.

- **Efficacy of Training Strategies:** Phase II of this pilot, the education and training component, was developed by each project team with limited input from DOE. As such, a wide variety of education and training strategies was developed and deployed, likely with varying degrees of success. However, this methodology was not designed to assess the efficacy of each individual strategy and instead could only assess whether the overall education and training package improved the rate of compliance. Designing a study to understand the efficacy of individual strategies (e.g., circuit rider) could be instrumental in shaping future training programs.

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Appendix A

Lessons Learned and Limitations

Appendix A

Lessons Learned and Limitations

A.1 Lessons Learned and Limitations

The following sections address lessons learned and study limitations, some of which are inherent to the methodology itself. In several cases, the DOE methodology has been adjusted to address issues that were discovered.

A.1.1 Applicability of Results

An inherent limitation of the study design is that the results (key item distributions, EUI, and measure-level savings) are statistically significant only at the state level. Other results, such as analysis based on climate zone level, reporting of non-key items (e.g., gas furnace efficiency), or further stratifications of the public data set, should not be considered statistically representative. A further area of study could be exploring conducting the sampling at the climate zone level.

A.1.2 Definition and Determination of Compliance

The methodology is based on a single site visit, which makes it impossible to know whether a particular home complies with the energy code in its entirety since not enough information can be gathered in a single site visit to know whether all code requirements have been met. This single site visit also makes it hard, if not impossible, to detect tradeoffs between building components unless all components involved in the tradeoff are clearly visible at the time of the site visit. (See discussion in Section A.1.5).

A.1.3 Site Access

Site access was purely voluntary, and data were collected only in homes where access was granted, which can be characterized as a self-selection bias. While every effort was made to limit this bias (i.e., sampling randomization, outreach to builders, reducing the burden of site visits, etc.), it is unavoidable due to the voluntary nature of the study. The impacts of this bias on the overall results are not known.

Site access (or site recruitment) appears to be a systemic issue in such studies as it has been noted anecdotally as a problem for several years in compliance studies completed around the country. This study was no different. The problems began right from the start as it was often difficult to even get a response from code officials, builders, or their representatives. And, even if a response was received, requests for access were often denied. One of the most common reasons given for request denial was fear of insurance liability.

While the project teams tried various approaches to deal with the issue, a single consistently effective solution was not found. In Kentucky, a retired building department official was hired to help with building recruitment and site access, and this appears to have had some success. Outreach campaigns were also used by several teams with various levels of success. A general best practice to engage the building industry through the development of a stakeholder group and regularly update this group on progress and potential issues with data collection was employed by most teams. This often resulted in new ideas that were tailored to specific state challenges.

A.1.4 Analysis Methods

All energy analysis was conducted using prototype models; no individually visited homes were modeled, as the self-imposed, one-visit-per-home limitation meant that not all necessary modeling inputs could be collected from a single home. Thus, the impact of certain field-observable factors such as size, height, orientation, window area, floor-to-ceiling height, equipment sizing, and equipment efficiency were not included in the analysis. In addition, duct leakage was modeled separately from the other key items due to limitations in the EnergyPlus™ software used for analysis. It should also be noted that the resulting energy consumption and savings projections are based on modeled data, and not on utility bills or actual home energy usage.

A.1.5 Presence of Tradeoffs

Field teams were able to gather only a minimal amount of data regarding which code compliance paths were being pursued for homes included in the study; all analyses therefore assumed that the prescriptive path was used. The project teams agreed that this was a reasonable approach. The overall dataset was reviewed in an attempt to determine if common tradeoffs were present, but the ability to do this was severely limited by the single site-visit principle, which did not yield complete data sets for a given home. To the extent it could be determined, it did not appear that there was a systematic presence of tradeoffs.

A.1.6 Measure-Level Savings

During the FOA study, each key item was examined individually to determine which had a significant number of observed values that did not meet the associated code requirement. Significant was defined as 15% or more of the observed values not meeting the associated code requirement. Only the items above this threshold were analyzed. However, if a measure met the 15% threshold in Phase I but not in Phase III, it was still included in the measure-level savings for Phase III regardless of the worse-than-code percentage so as not to potentially overstate savings by ignoring the reduced, but not necessarily zero, measure-level savings in Phase III. Upon further consideration, the 15% cutoff was removed from the DOE methodology following the completion of the study, and future studies will include consideration of all non-compliant values.

Another limitation of the study is that the measure-level savings estimates for multiple years are simply the annual savings multiplied by 15, 55, and 465 for 5-year, 10-year, and 30-year savings, respectively. The savings therefore do not take into account factors such as fuel price escalation, the time value of money, potential changes in construction volume over time, or changes in emission factors associated with the electrical grid over time, etc. Emissions calculations are done using national average emissions rates for electricity, while there is actually significant variation between states.

Lastly, several factors were held constant to minimize the variability between the Phase I and Phase III analyses that could be attributed to the study methodology and that might obscure the impact of actual changes in the key items. These include state energy fuel prices; annual number of permits estimated for the state; split of permits between climate zones in multi-climate zone states; distribution of heating system types in the state; distribution of foundation types in the state; and number of observations of key items per climate zone in multi-climate zone states used in the Monte Carlo simulations.

A.1.7 Interactive Effects

The approach taken in the study results in an estimate of savings potential for each measure as it does not take "interaction effects" into account such as the increased amount of heating needed in the winter when energy efficient lights are installed. A building's energy consumption is a dynamic and interactive process that includes all the building components present within a given home. In a typical real building, the savings potential might be higher or lower; however, additional investigation indicated that the relative impact of such interactions in these homes is very small and could safely be ignored without changing the basic conclusions of the analysis.

A.1.8 Sample Substitutions

The DOE methodology is based on a random sampling protocol. Census Bureau data[1] are the preferred basis of a state sampling plan if it is available at the county and place[2] level and covers the entire state. Of course, as is often the case with field-based research, substitutions to the state sampling plan were sometimes needed to fulfill the complete data set. One common reason for substitutions was lack of construction in a particular area. Project teams were allowed to substitute jurisdictions with similar socio-economic status, within the same climate zone, and with a similar level of enforcement. Following a situation where a project team substituted less than a complete set of observations for a key item, the guidance was modified to note that substitutions need to be for a complete set of observations of all key items. The guidance also noted that the substitutions must be acceptable to the project team and all its stakeholders and that all substitutions must be documented.

A.1.9 Data Collection and Quality

Not surprisingly, there were several lessons learned regarding data collection and data quality. The study showed that data collector training referenced in the DOE methodology is critical. The main reason is to ensure all collectors have a common understanding of the data to be collected and how the data are to be recorded. Even though most if not all of the project teams conducted this training, there were several pervasive issues.

One common inconsistency across project teams was the entering of numeric values in a text field or vice versa. Compounding this and other similar issues, the project teams did not always review the data before the end of the project, making it too late to correct the issues. The DOE methodology was modified to include steps to send the data to PNNL for review at 20%, 50%, and 75% of data collection so any common issues could be addressed before data collection completion.

Modifications to the basic data collection form were made over the course of the study to attempt to mitigate some of the most common inconsistency issues. Changes included modifying the form to use dropdown lists for selections of as many items as possible, such as units.

One mitigating strategy that assisted in the resolution of data inconsistencies was that many project teams took pictures while onsite. These pictures proved very useful during the formal QA/QC process undertaken by PNNL.

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[1] Available at http://www.census.gov/construction/bps. Select "Building Permits" data. Documentation on obtaining these data may be found at the same link.
[2] "Places" are cities and areas within counties designated in the Census Bureau data. These "places" may or may not correspond to jurisdictions.

Data outliers (values that fall outside of the expected range for an observation) also proved to be an issue. Such data outliers can be the result of errors (by the builder or the field team) or they may simply be extreme but valid data points. Many outliers were observed in duct leakage test results and were of particular concern. There were several occasions where test equipment readings were inexplicably high, and data recorders simply noted the reading (or entered the highest reading the equipment could register if the equipment did not yield a result) without providing suitable comments to identify or clarify the possible reason for abnormalities. Given that this was a research study, and in many cases valid extremes do exist in the field, it was decided to retain all data outliers in the analysis. However, the DOE methodology and related tools (e.g., data collection forms) were updated to help guide future data collection teams in proactively identifying potential outliers and to the greatest extent possible verifying (or mitigating) their impacts while still in the field.

Lastly, some teams chose to collect very little of the non-key item data, especially in Phase III. Although collecting this data is not an explicit requirement , it represents an important opportunity to gather key information on the building. Once onsite, collecting all of the non-key data available adds relatively little time and expense. The DOE methodology states that all available data should be collected as these data can be valuable to the stakeholders. Future requestors of DOE support for similar studies (i.e., PNNL assistance with sampling activities and data analysis) will be required to commit to collecting as much non-key data as possible, in addition to committing to use the DOE methodology and making the study data and results publicly available.

A.1.10 Insulation Installation Quality

At the start of the project, insulation installation quality (IIQ) was noted as a particular concern among project teams and stakeholders as it plays an important role in the energy performance of envelope assemblies. Although IIQ is not a key item by itself, IIQ was collected in the field and used to modify the energy contribution from ceiling, wall, and foundation insulation. As noted in Section 5.0, the study results confirmed that IIQ is an area of concern and needs focused education and training. The study only considered IIQ for cavity insulation as the RESNET protocol[3] at the time the study began did not include grading of continuous insulation.

[3] See the January 2013 version at https://www.resnet.us/wp-content/uploads/RESNET-Mortgage-Industry-National-HERS-Standards_3-8-17.pdf; the current version at the time the study began.

Appendix B

Additional Key Item Data

Appendix B

Additional Key Item Data

B.1 Additional Key Item Data

Additional analysis was conducted on the key items that were not included in the main body of this report. Specifically, given the numerous foundation types within each state, a specific analysis of each foundation type is captured in this appendix.

B.1.1 Foundation Insulation

While initially combined into a single key item (i.e., foundation assemblies[1]), the variety of observed foundation types is disaggregated in this section and data are presented for each foundation type. The three predominant foundation types observed across the seven states are conditioned basements, floors, and slab on grade.

Figure B.1 and Figure B.2 compare basement walls and floors by assembly U-factor and compliance rate. These assemblies consider cavity and continuous insulation layers, framing factors and the IIQ observed in the field. Figure B.3 depicts slab edge R-value with an accompanying compliance rate in Table B.3.

[1] Floor insulation, basement wall insulation, and slab insulation were combined into a single key item of foundation insulation.

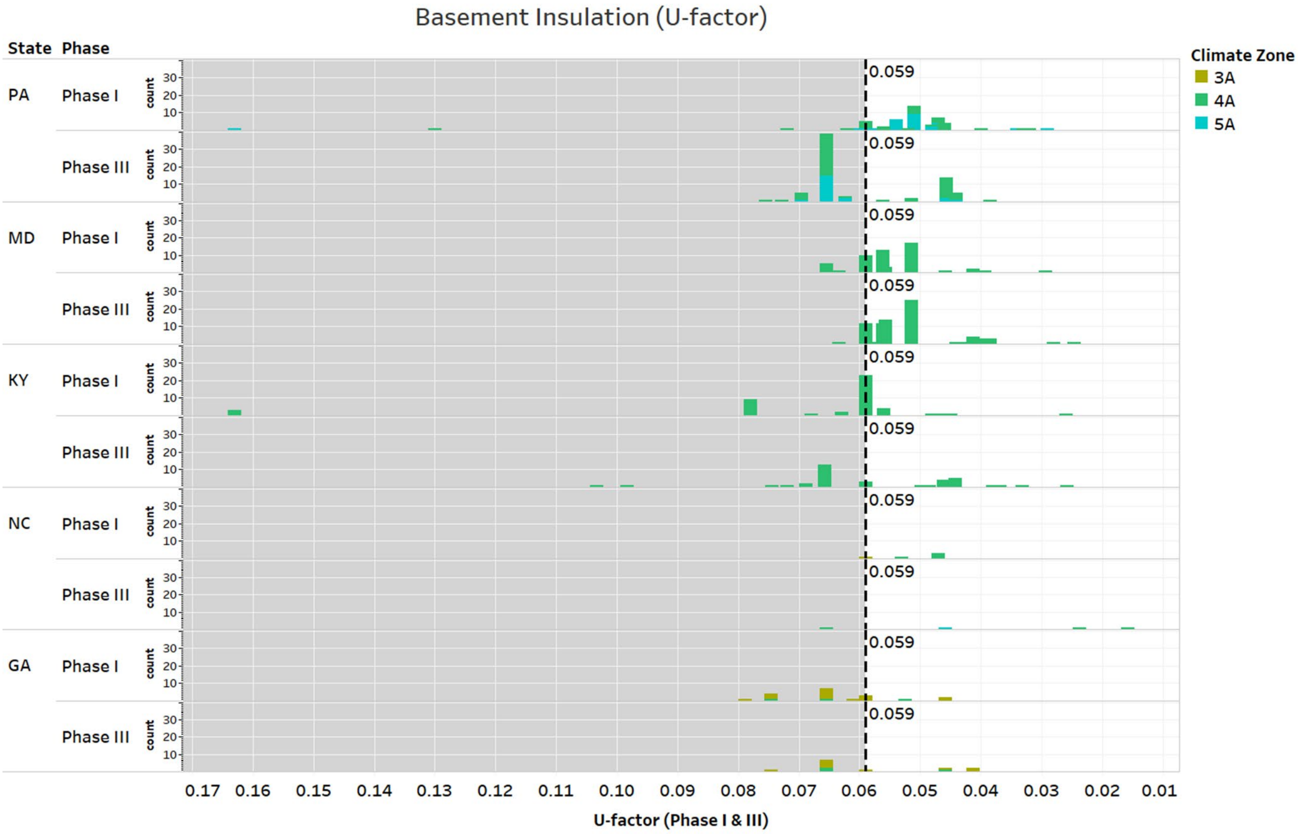

Figure B.1. Basement Insulation U-factor Phase I and Phase III Comparison

Table B.1. Phase I and Phase III Basement Insulation U-factor Compliance Rate

State	Code Requirement (U-factor)	Phase I (Compliance Rate)	Phase III (Compliance Rate)
Pennsylvania	U-0.059	42 of 53 (79%)	26 of 75 (35%)
Maryland	U-0.059	49 of 55 (89%)	79 of 80 (99%)
Kentucky	U-0.059	8 of 46 (18%)	26 of 44 (59%)
North Carolina	U-0.059	-	-
Georgia	U-0.059	6 of 19 (32%)	5 of 13 (38%)
Alabama	-	-	-
Texas	-	-	-

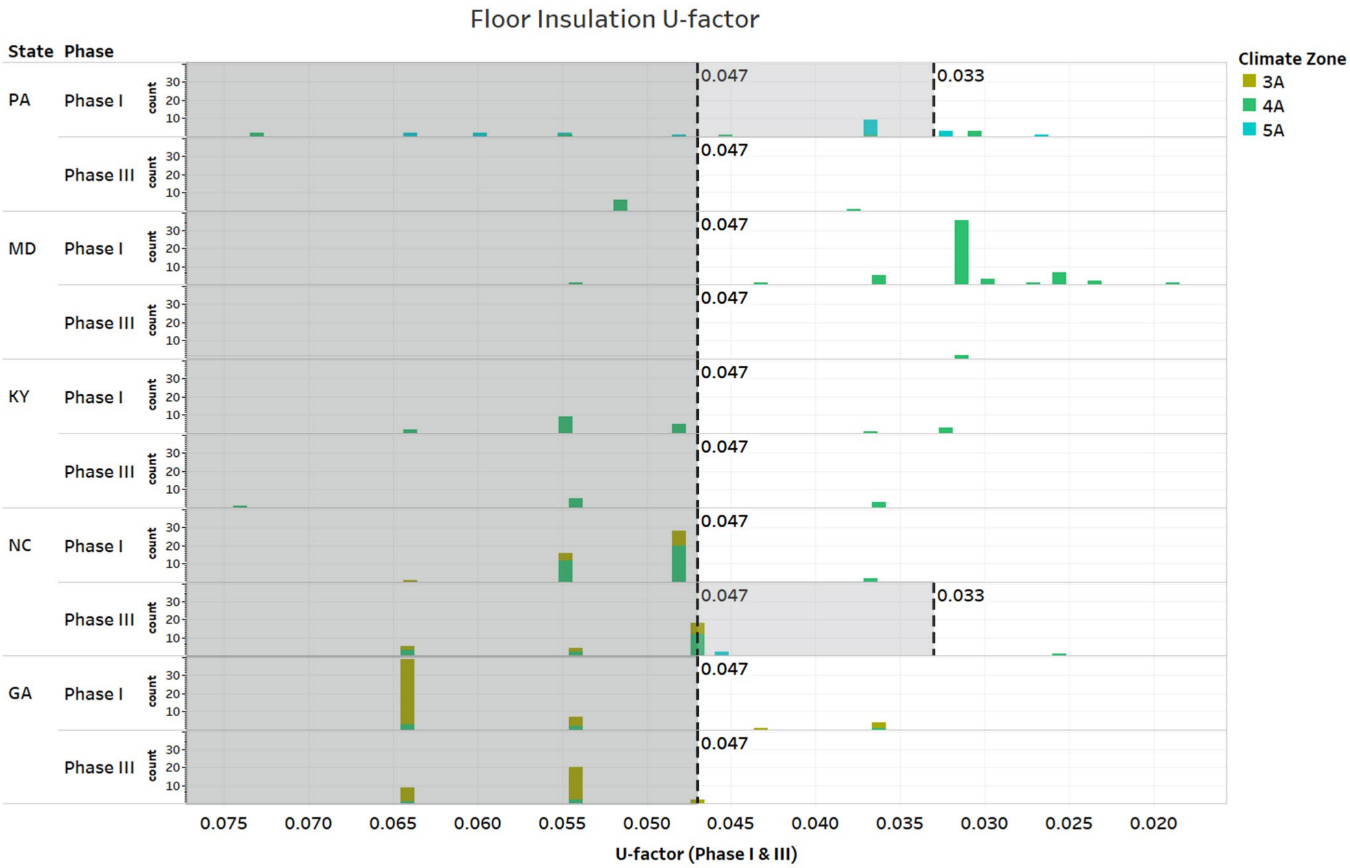

Figure B.2. Floor Insulation U-factor Phase I and Phase III Comparison

Table B.2. Phase I and Phase III Floor Insulation U-factor Compliance Rate

State	Code Requirement (U-factor)	Phase I (Compliance Rate)	Phase III (Compliance Rate)
Pennsylvania	CZ4 (0.047); CZ5 (0.033)	9 of 29 (31%)	1 of 7 (14%)
Maryland	U-0.047	56 of 57 (98%)	2 of 2 (100%)
Kentucky	U-0.047	4 of 20 (20%)	3 of 14 (21%)
North Carolina	CZ4 (0.047); CZ5 (0.033)	28 of 47 (60%)	19 of 30 (63%)
Georgia	U-0.047	5 of 51 (10%)	2 of 31 (6%)
Alabama	-	-	-
Texas	-	-	-

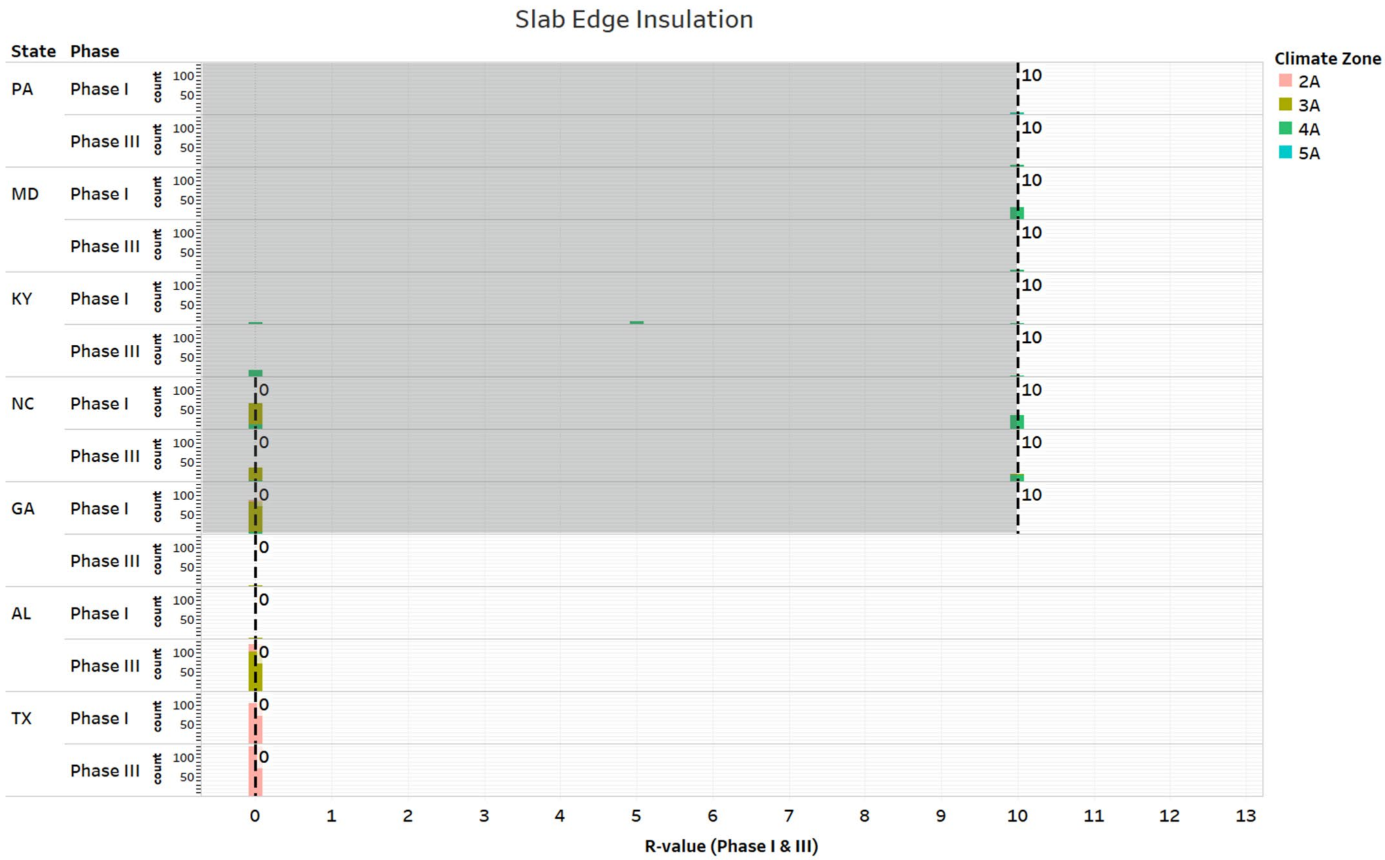

Figure B.3. Slab Edge Insulation R-values Phase I and Phase III Comparison

Table B.3. Phase I and Phase III Slab Edge Insulation R-value Compliance Rate

State	Code Requirement (R-value)	Phase I (Compliance Rate)	Phase III (Compliance Rate)
Pennsylvania	10	6 of 7 (86%)	5 of 5 (100%)
Maryland	10	32 of 32 (100%)	6 of 6 (100%)
Kentucky	10	2 of 10 (20%)	2 of 10 (20%)
North Carolina	CZ3 (0); CZ4 (10)	91 of 104 (88%)	52 of 55 (95%)
Georgia	CZ3 (0); CZ4 (10)	-	-
Alabama	-	-	-
Texas	-	-	-

B.2 Additional Analysis

Additional analysis comparing key and non-key measures is presented at the state level in this section. The following sections provide more insight on trends identified in Section 4.2 of this report.

B.2.1 Visual Inspection vs. Blower Door Test

Table B.4 compares the observed compliance rate when using a visual inspection versus a blower door test across all states. As shown in Table B.4, visual inspection is not a good indicator for envelope tightness compliance in any state, especially those with a more stringent leakage rate.

Table B.4. State Air Tightness Visual Inspection vs. Blower Door Test (Phase I & III)

State	Code Requirement	Compliance Rate based on Visual Inspection	Compliance Rate based on Performance Test
PA	≤7 ACH50 (n=133)	75.0%	89.5%
MD	≤3 ACH50 (n=134)	98.5%	56.7%
KY	≤7 ACH50 (n=129)	71.0%	82.9%
NC	≤5 ACH50 (n=130)	86.8%	82.3%
GA	≤7 ACH50 (n=141)	57.5%	97.9%
AL	≤5 ACH50 (n=128)	60.1%	48.4%
TX	≤5 ACH50 (n=130)	81.8%	76.2%

B.2.2 Duct Tightness: Unconditioned vs. Conditioned Space

Table B.5 compares tightness levels of systems with ducts in 100% conditioned space vs. those with ducts in unconditioned space across all states. An observation from the analysis in Section 4.2 is that states with a duct leakage rate of 12 cfm25/100 ft^2 had much leakier ducts in conditioned space than those with a 4 cfm25/100 ft^2 requirement. As shown in Table B.5, Pennsylvania and Kentucky are the key drivers for significantly leakier ducts in conditioned space, while Georgia had moderate leakage in conditioned space.

Table B.5. State Average Duct Tightness by Code Requirement: Unconditioned vs. Conditioned Space (Phase I & III)

State	Code Requirement (cfm25/100 ft^2)	Average Duct Tightness (Unconditioned Space)	Unconditioned Space Sample Size (n)	Average Duct Tightness (100% Conditioned Space)	100% Conditioned Space Sample Size (n)
PA	12	16.9	114	29.8	19
MD	4	4.3	131	4.2	28
KY	12	12.8	92	21	48
NC	6	6.3	139	4.1	7
GA	12	10.2	131	12.9	7
AL	4	7.7	143	7.1	12
TX	4	5.4	135	3.6	20

Appendix C

Education and Training

Appendix C

Education and Training

C.1 Detailed Education and Training

Table C.1 contains the types of training activities by state for Phase II.

Table C.1. Phase II Education and Training Activities

State	Type of Training Activity
Alabama	High-efficacy lighting infographic and builder brochure
	In-person training at HBA
	Duct and envelope tightness training
	Energy specialist training
Georgia	Online learning modules: duct leakage, insulation installation, lighting
	Tech tips: lighting, duct leakage, insulation installation, real estate
	DET Quick Check Tool for Code Officials
	In-person training
Kentucky	In-person
	Circuit rider assistance one-on-one meetings
	Circuit rider in-field contacts
	YouTube videos
	Project overview presentations
Maryland	Circuit Rider
	Code Coach Handouts: airtightness, duct testing, ERI, insulation and windows, lighting, ducts
	Energy Rating Index Exercise
	Sample plans
	2015 IECC in-person training
	Key Item Fact Sheets: sealing rim joists and sill plates and lighting
	Lighting Box Model
	Newsletters
	Postcard
	Webinar: Ventilation Strategies
North Carolina	Videos
	Online Promotion – Energy Code Essentials/Coffee
	In-person training with HBA
	Energy Code Compliance Guides (1 and 2-page)
	Presentations at conferences
	Energy code photo library

State	Type of Training Activity
	Insulation installation training
	Postcards
Pennsylvania	Energy code plan review training
	Keys to effective energy code implementation training
	Energy Code Jeopardy!
	Webinars
	Fact Sheets: duct leakage, insulation, lighting
	Fillable residential energy plans
	Verification forms: air sealing, duct sealing
	Postcards
	E-CODE Assistant app
Texas	2015 Energy Code Adoption Toolkit
	Factsheets: Lighting, duct leakage, envelope sealing, insulation R-value and quality, HVAC system design and sizing

Appendix D

Additional Non-Key Item Data

Appendix D

Additional Non-Key Item Data

D.1 Additional Data Collected by Field Teams

The project teams made observations on several energy efficiency measures beyond the key items alone. The majority of these additional items are based on code requirements within the states, while others were collected to inform the energy simulation and analysis for the project (e.g., installed equipment). While these items were not the focal point of the study, and many are not considered statistically representative, they do provide some valuable insight surrounding the energy code and residential construction within the state.[1]

The following is a sampling of the additional data items collected as part of the seven state field studies. Each item is presented, along with a brief description and statistical summary based on the associated field observations. The full data set is available on the DOE Building Energy Codes Program website.[2]

D.1.1 General

The following represents the general characteristics of the homes observed in the seven studies:

D.1.1.1 Average Home

Table D.1 lists the average home characteristics for the seven states.

Table D.1. Average Home Characteristics

Phase	Home Statistics	AL	GA	KY	MD	NC	PA	TX
Phase I	Average Square Footage (ft^2)	2,552	2,859	2,401	3,232	2,730	2,882	2,708
	Average # of Stories	1.5	2.2	1.3	2.3	1.8	2.1	1.8
	Average # of Bedrooms	NA	NA	NA	3.8	3.7	NA	NA
	Homes Visited	134	216	140	207	249	171	133
Phase III	Average Square Footage (ft^2)	2,227	2,923	2,897	3,856	2,411	2,645	2,680
	Average # of Stories	1.4	1.9	1.6	2.2	1.8	2.1	1.8
	Average # of Bedrooms	3.6	4.2	3.3	3.9	3.7	3.2	3.7
	Homes Visited	126	139	128	185	134	160	136

Figure D.1, Figure D.2, and Figure D.3 show the conditioned floor area, number of stories, and number of bedrooms for Phases I and III.

[1] This section is intended to provide a snapshot of additional data that was collected by project teams in each state. However, as indicated by the number of observations represented in each graph and table in this section, this additional data was not always collected.
[2] Available at https://www.energycodes.gov/compliance/energy-code-field-studies

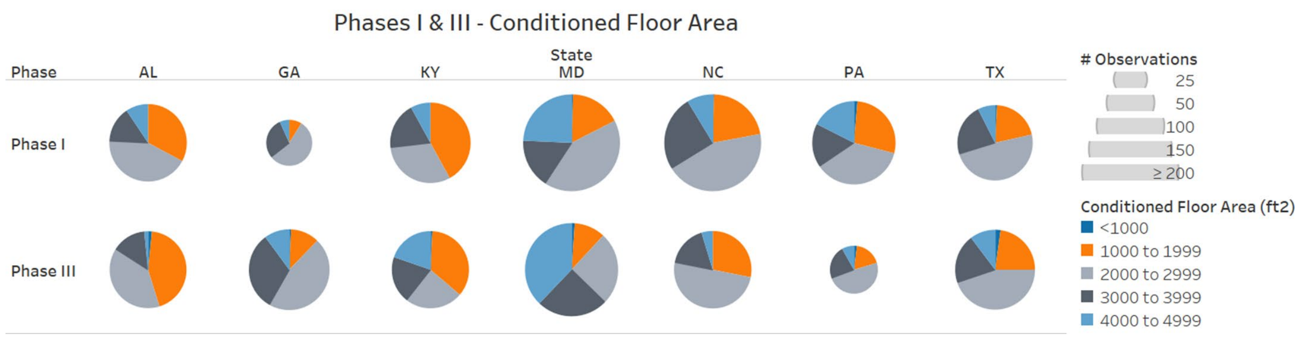

Figure D.1. Conditioned Floor Area (ft^2)

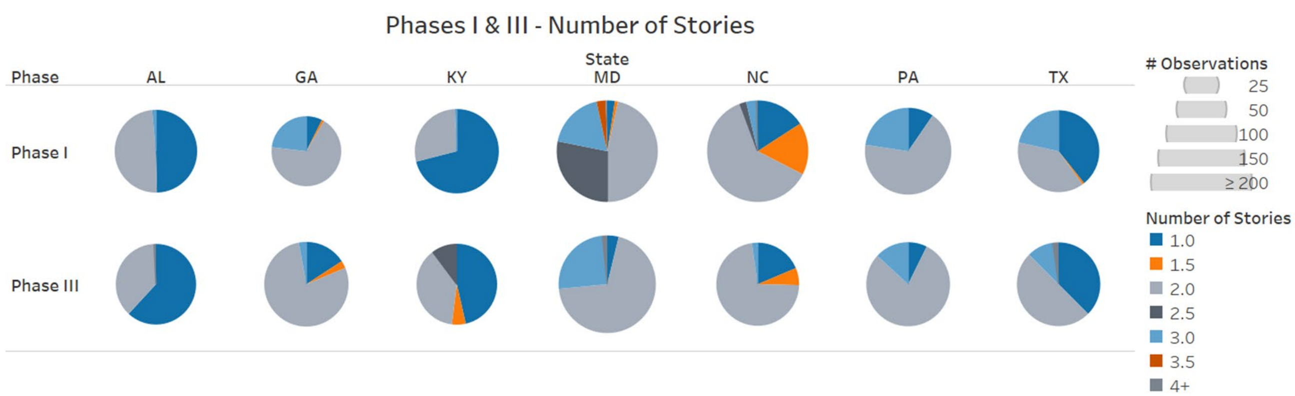

Figure D.2. Number of Stories

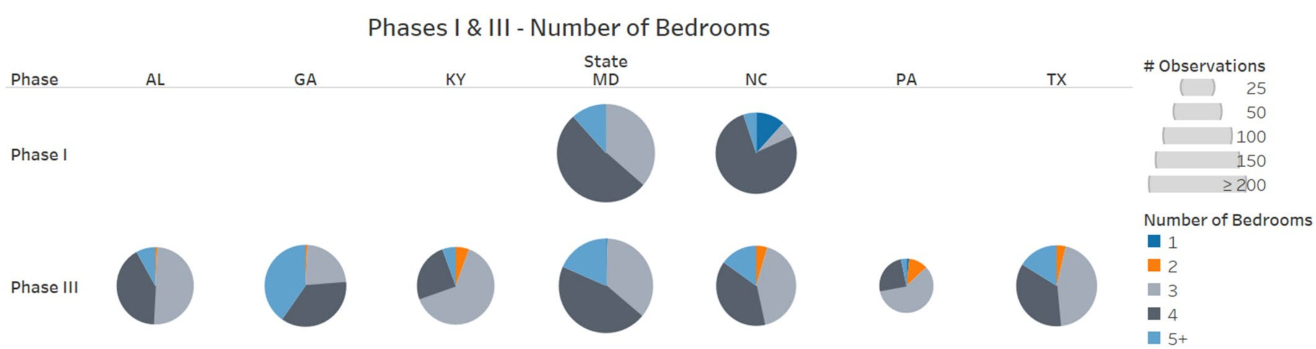

Figure D.3. Number of Bedrooms

D.1.1.2 Wall Profile

Table D.2 and Figure D.4 show the wall characteristics and types of wall insulation.

Table D.2. Wall Characteristics

Phase	Wall Characteristics		AL	GA	KY	MD	NC	PA	TX
Phase I	Framing Type	Frame Walls	100%	99%	98%	99%	100%	100%	99%
		Mass Walls	0%	1%	2%	1%	0%	0%	1%
	Framing Material	Wood	100%	100%	98%	99%	100%	100%	100%
		Steel	0%	0%	2%	1%	0%	0%	0%
	Framing Depth	4 inch	93%	94%	90%	54%	86%	56%	97%
		6 inch	7%	6%	10%	46%	14%	44%	3%
Phase III	Framing Type	Frame Walls	100%	100%	100%	99%	100%	100%	100%
		Mass Walls	0%	0%	0%	1%	0%	0%	0%
	Framing Material	Wood	100%	100%	100%	100%	99%	100%	100%
		Steel	0%	0%	0%	0%	1%	0%	0%
	Framing Depth	4 inch	NA	100%	89%	NA	81%	71%	97%
		6 inch	NA	0%	11%	NA	19%	29%	3%

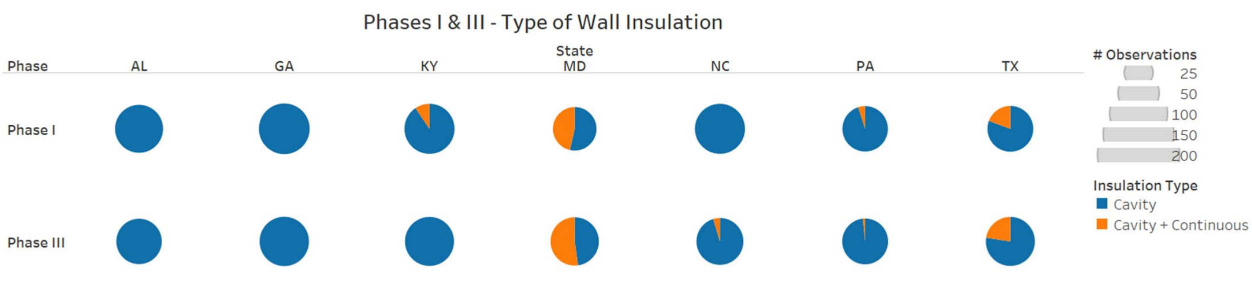

Figure D.4. Type of Wall Insulation

D.1.1.3 Foundation Profile

Figure D.5 shows the foundation types by state.

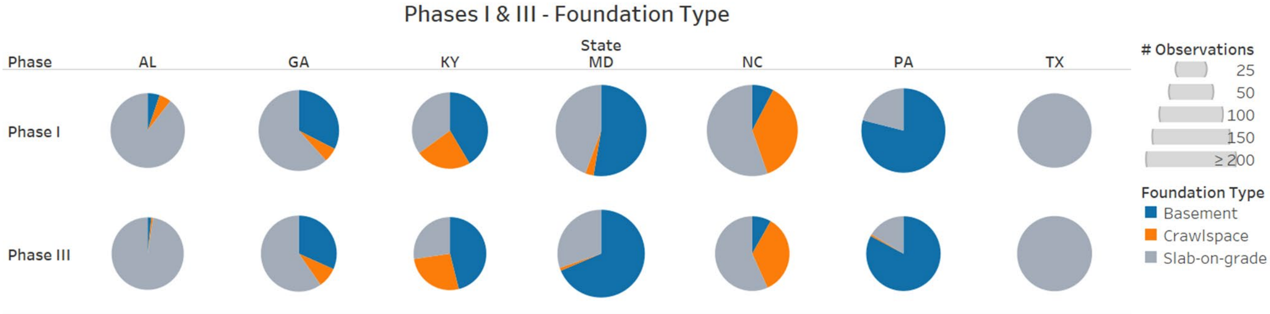

Figure D.5. Predominant Foundation Type

D.1.1.4 Builder Profile

Figure D.6 displays the number of homes built annually by builders who participated in the study.

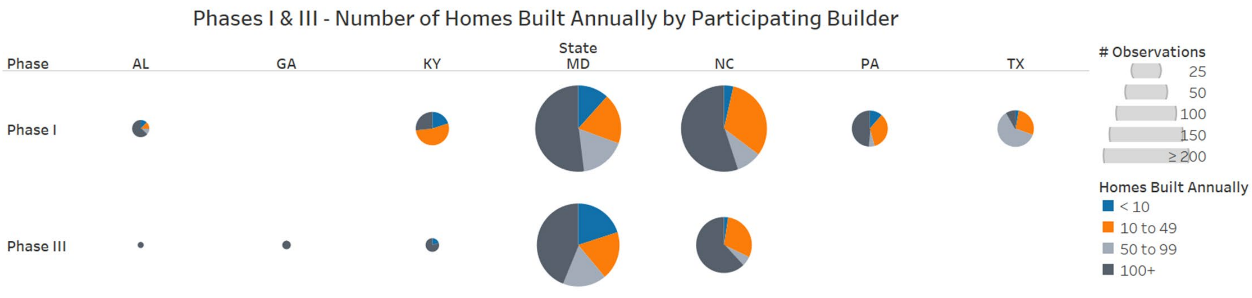

Figure D.6. Number of Homes Built Annually by Participating Builder

D.1.2 Compliance

The following summarizes information related to compliance, including the energy code associated with individual homes (Figure D.7), and whether an energy code certificate was posted (Figure D.8) and if a programmable thermostat was installed (Figure D.9). The percentages provided in the sections below represent percentages of total observations or the percentage of observations that complied.

D.1.2.1 Energy Code Used

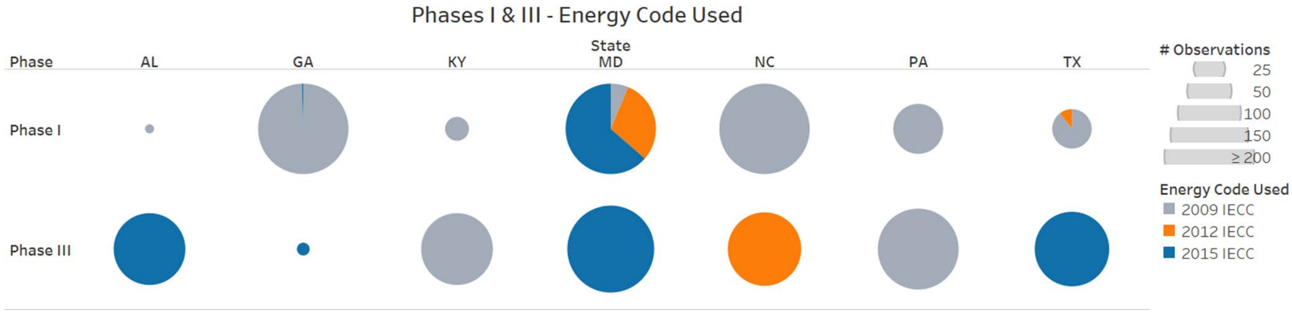

Figure D.7. Energy Code Used

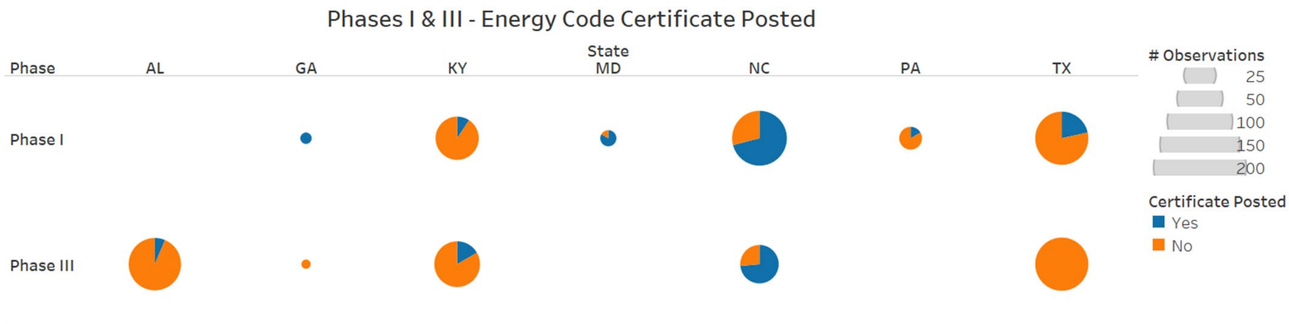

Figure D.8. Energy Code Certificate Posted

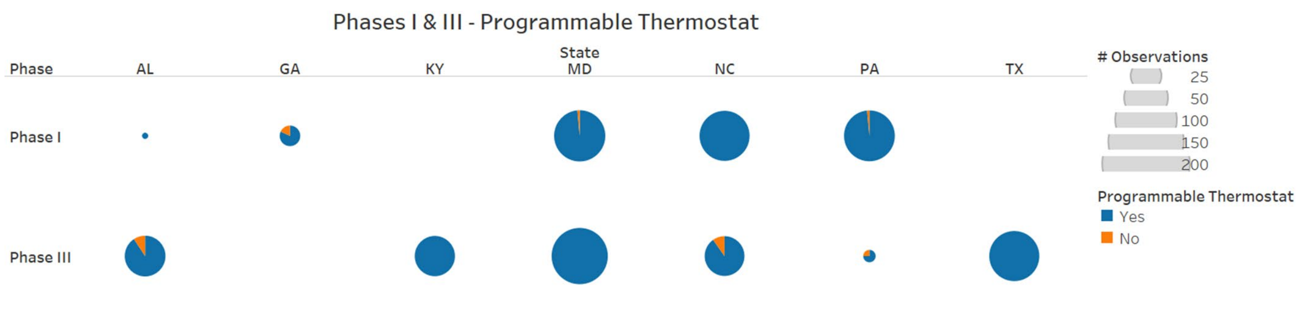

Figure D.9. Programmable Thermostat Installed

D.1.3 Envelope

Table D.3 shows the characteristics of the thermal envelope:

Table D.3. Thermal Envelope Characteristics

Phase	Thermal Envelope Characteristic		AL	GA	KY	MD	NC	PA	TX
Phase I	Insulation Labeled?	Yes	77%	100%	85%	99%	88%	96%	97%
		No	23%	0%	15%	1%	12%	4%	3%
	Correct Attic hatch/door insulation?	Yes	7%	81%	40%	26%	NA	69%	42%
		No	93%	19%	60%	74%	NA	31%	58%
	Air Sealing in accordance with checklist?[a]	Thermal Envelope	48%	42%	85%	100%	NA	74%	74%
		Fenestration	94%	69%	84%	100%	NA	26%	96%
		Openings around doors and windows	97%	73%	83%	100%	92%	95%	96%
		Utility penetrations	80%	71%	81%	98%	89%	88%	93%
		Dropped ceilings	36%	NA	90%	88%[b]	86%	97%	74%
		Knee walls	46%	38%	75%	74%	95%	67%	67%
		Garage walls	70%	30%	82%	83%	81%	82%	92%
		Tubs and showers	53%	100%	70%	81%	81%	57%	92%
		Attic access openings	NA	63%	41%	65%	NA	3%	82%
		Rim joists	NA	67%	72%	100%	NA	56%	87%
		Other sources of infiltration	NA	33%	79%	100%	74%	94%	71%
		IC-rated light fixtures	81%	NA	100%	99%	93%	84%	98%
Phase III	Insulation Labeled?	Yes	100%	33%	95%	100%	91%	42%	99%
		No	0%	77%	5%	0%	9%	58%	1%
	Correct Attic hatch/door insulation?	Yes	26%	100%	17%	100%	26%	95%	2%
		No	74%	0%	83%	0%	74%	5%	98%
	Air Sealing in accordance with checklist?	Thermal Envelope	33%	100%	44%	100%	NA	93%	59%
		Fenestration	100%	100%	100%	100%	NA	NA	100%
		Openings around doors and windows	97%	100%	97%	100%	92%	100%	96%
		Utility penetrations	78%	NA	67%	100%	89%	91%	100%
		Dropped ceilings	61%	NA	56%	100%	80%	0%	93%
		Knee walls	57%	100%	59%	NA	72%	67%	96%
		Garage walls	82%	NA	94%	100	88%	92%	65%
		Tubs and showers	75%	100%	76%	100%	88%	NA	91%
		Attic access openings	NA	NA	47%	100%	NA	61%	93%
		Rim joists	NA	100%	64%	100%	NA	100%	94%

Phase	Thermal Envelope Characteristic		AL	GA	KY	MD	NC	PA	TX
		Other sources of infiltration	NA	100%	55%	100%	67%	100%	84%
		IC-rated light fixtures	99%	NA	93%	100%	78%	NA	100%

(a) Note that results in this section are from checklist items that are addressed via visual inspection. When comparing these visual results with the actual tested results, it is clear that there can be significant differences in the two methods.
(b) The project team notes that dropped ceilings in attic spaces are extremely rare in Maryland. This requirement includes "dropped ceilings or chases" and the vast majority of the observations were for chases.

D.1.4 Duct & Piping Systems

Table D.4 represents an average profile of observed air ducting and water piping systems, followed by a list of additional questions and answers by percentage related to duct systems in Table D.5.

Table D.4. Duct & Piping System Characteristics

Phase	Duct & Piping System Characteristic		AL	GA	KY	MD	NC	PA	TX
Phase I	Duct location in conditioned space (average percentage)	Supply	17%	30%	48%	67%	30%	76%	34%
		Return	24%	26%	51%	76%	32%	78%	34%
	Ducts entirely in conditioned space	Supply	17%	4%	40%	27%	7%	35%	5%
		Return	24%	4%	41%	61%	10%	48%	7%
	Ducts in unconditioned space insulation (R-value)	Supply	8.0	8.0	7.3	7.5	8	5.9	6.0
		Return	7.8	8.0	6.7	7.4	8	5.5	6.0
	Ducts in attic insulation (R-value)	Supply	8.1	8	7.7	7.4	NA	NA	6.1
		Return	7.9	7.3	7.1	7.4	NA	NA	6.1
	Pipe insulation (R-value)	Average	R-2.4	R-2	R-2.4	R-3	R-3.3	R-3.2	R-2.7
		Range	R-0 to R-5	R-0 to R-2	R-2 to R-3	All R-3	R-0 to R-5	R-0 to R-5	R-2 to R-3
Phase III	Duct location in conditioned space (average percentage)	Supply	16%	32%	55%	58%	27%	73%	41%
		Return	17%	33%	59%	59%	27%	73%	40%
	Ducts entirely in conditioned space	Supply	16%	14%	36%	24%	6%	7%	16%
		Return	17%	15%	35%	26%	6%	25%	16%
	Ducts in unconditioned space insulation (R-value)	Supply	NA	NA	7.2	8.0	8.0	5.4	6.0
		Return	8.0	NA	7.3	8.0	8.0	5.3	6.0
	Ducts in attic insulation (R-value)	Supply	8.0	NA	7.2	8.0	7.9	6.2	6.2
		Return	7.7	NA	7.2	8.0	7.9	10.0	6.2
		Average	R-2.8	NA	R-3	NA	R-3.2	NA	R-3

Phase	Duct & Piping System Characteristic		AL	GA	KY	MD	NC	PA	TX
	Pipe insulation (R-value)	Range	R-0 to R-5	NA	All R-3	NA	R-0 to R-9	NA	R-3 to R-3

Table D.5. Duct System Sealing

Phase	Duct & Piping System Characteristic	AL	GA	KY	MD	NC	PA	TX
Phase I	Building cavities used as supply ducts	97%	NA	4%	4%	5%	74%	0%
	Air ducts sealed	91%	NA	81%	91%	97%	85%	83%
	Air handlers sealed	82%	60%	87%	71%	90%	93%	90%
	Filter boxes sealed	77%	20%	85%	57%	95%	79%	90%
	Average leakage rate (Unadjusted CFM25/100 ft^2)	8.0	10.9	13.0	4.7	5.8	21.3	6.9
Phase III	Building cavities used as supply ducts	99%	NA	7%	0%	9%	100%	1%
	Air ducts sealed	97%	NA	73%	100%	93%	86%	98%
	Air handlers sealed	98%	NA	96%	100%	89%	34%	97%
	Filter boxes sealed	90%	NA	86%	100%	94%	34%	98%
	Average leakage rate (Unadjusted CFM25/100 ft^2)	7.1	9.7	17.8	3.8	6.6	15.3	3.7

D.1.5 HVAC Equipment

The following represents an average profile of observed HVAC equipment, followed by a list of additional questions related to such systems.

D.1.5.1 Heating

Figure D.10 and Table D.6 show heating fuel sources, types, and equipment characteristics by state.

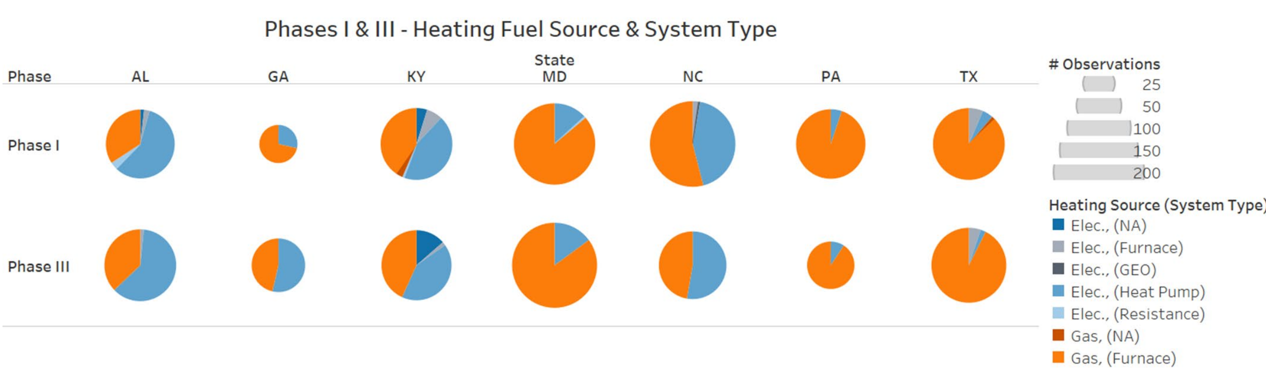

Figure D.10. Heating Fuel Source & System Type

Table D.6. Heating Equipment Characteristics

Phase	Duct & Piping System Characteristic		AL	GA	KY	MD	NC	PA	TX
Phase I	Average System Capacity (Btu/hr)	Furnace	73,300	76,900	59,600	64,000	72,000	70,065	83,000
		Heat Pump	43,200	76,500	39,000	32,500	42,700	NA	54,000
		Electric Resistance	59,500	NA	48,000	NA	NA	NA	NA
	Average System Efficiency	Furnace (AFUE)	83	82	88	93	84	93	83
		Heat Pump (HSPF)	13	8.3	8.2	8	12.6	9	8.8
Phase III	Average System Capacity (Btu/hr)	Furnace	NA	NA	NA	NA	56,600	91,000	73,100
		Heat Pump	NA	NA	NA	NA	29,900	NA	22,750
		Electric Resistance	NA	NA	NA	NA	NA	NA	NA
	Average System Efficiency	Furnace (AFUE)	NA	NA	NA	NA	84.5	92	82
		Heat Pump (HSPF)	NA	NA	NA	NA	18.5	9	NA

D.1.5.2 Cooling

Figure D.11 and Table D.7 show cooling system types and equipment characteristics by state.

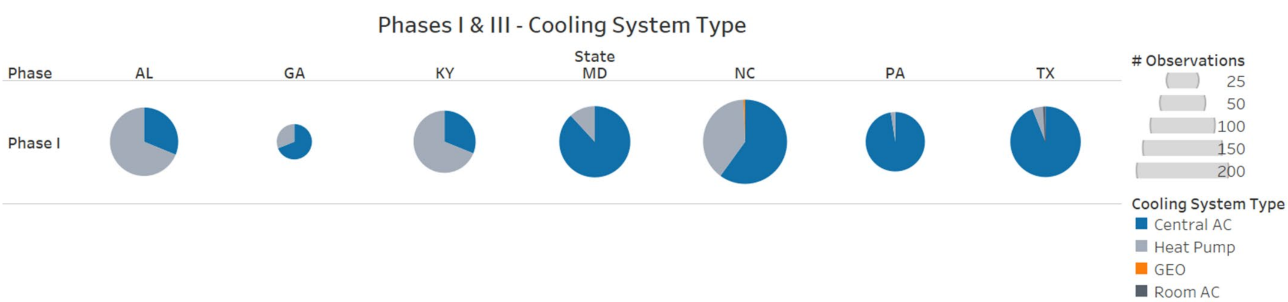

Figure D.11. Cooling System Type[1]

Table D.7. Cooling Equipment Characteristics

Phase	Duct & Piping System Characteristic		AL	GA	KY	MD	NC	PA	TX
Phase I	Average System Capacity (Btu/hr)	Central AC	41,300	40,600	40,000	32,000	45,300	33,000	52,800
		Air Conditioning	51,000						
		Heat Pump	43,000	76,500	38,000	25,800	36,800		50,000
		Central AC	13	13.8	13.7	13.2	13.9	13.3	15

[1] Data on cooling system type and equipment characteristics were not collected in Phase III.

Phase	Duct & Piping System Characteristic		AL	GA	KY	MD	NC	PA	TX
	Average System Efficiency (SEER)	Air Conditioning	13						
		Heat Pump	13.4			13.0			16
Phase III	Average System Capacity (Btu/hr)	Central AC			34,000		35,600	28,400	39,600
		Air Conditioning							
		Heat Pump			31,600		29,600	42,000	
	Average System Efficiency (SEER)	Central AC					14.4	13	14.7
		Air Conditioning							
		Heat Pump			41.1				

D.1.5.3 Water Heating

Figure D.12, Figure D.13, Figure D.14, and Table D.8 summarize hot water sources, systems, equipment characteristics, and storage capacity by state.

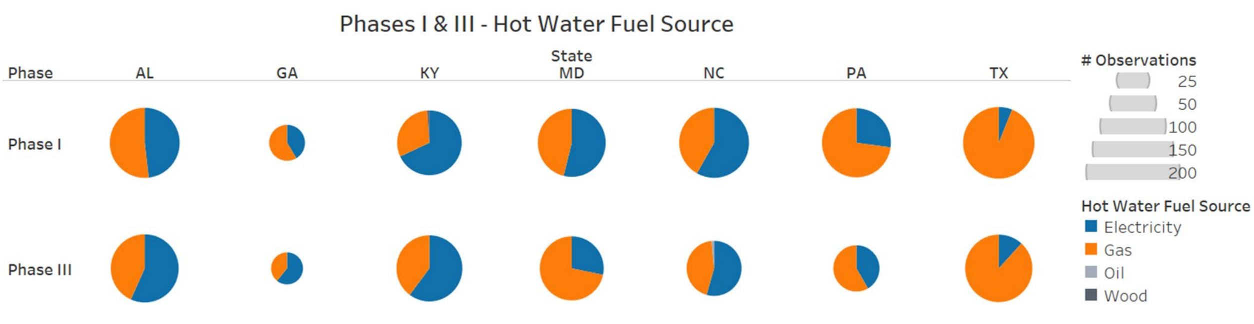

Figure D.12. Hot Water Fuel Source

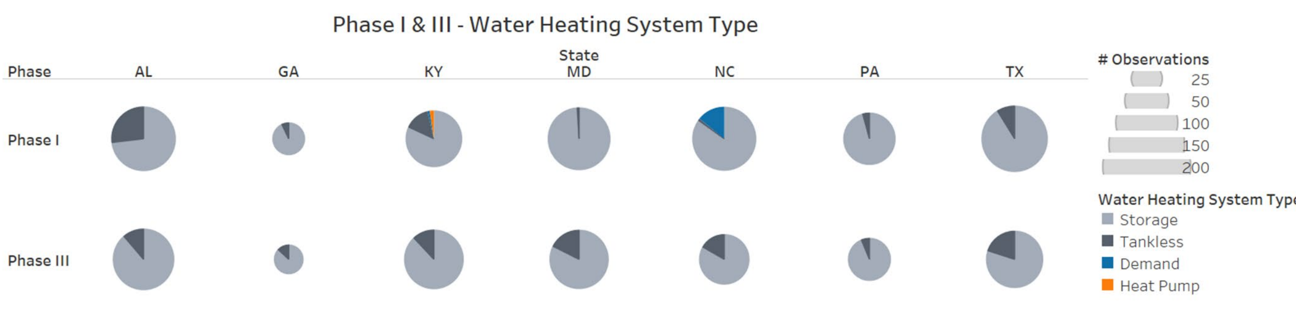

Figure D.13. Water Heating System Type

Table D.8. Water Heating Equipment Characteristics

Phase	Water Heating Equipment Characteristics		AL	GA	KY	MD	NC	PA	TX
Phase I	Average System Capacity (gal)		52	57	54	62	53	55	54
	Average System Efficiency (EF)	Electric Storage (non-heat pump)	0.91	0.90	0.91	0.90	NA	0.91	0.86
		Electric Storage (heat pump)	2.4	NA	2.75	NA	NA	NA	NA
		Electric Tankless	NA	NA	0.9	NA	NA	NA	NA
		Gas Storage	0.69	0.59	NA	0.65	NA	0.66	0.63
		Gas Tankless	0.86	0.82	0.89	0.94	NA	0.94	0.69
Phase III	Average System Capacity (gal)		52	52	53	56	47	51	49
	Average System Efficiency (EF)	Electric Storage (non-heat pump)	0.89	0.94	0.93	0.93	NA	0.91	0.92
		Electric Storage (heat pump)	NA	NA	2.1	NA	NA	NA	NA
		Electric Tankless	NA	NA	NA	NA	NA	NA	NA
		Gas Storage	0.69	0.62	0.71	0.67	NA	NA	0.63
		Gas Tankless	NA	0.83	0.94	0.97	NA	NA	NA

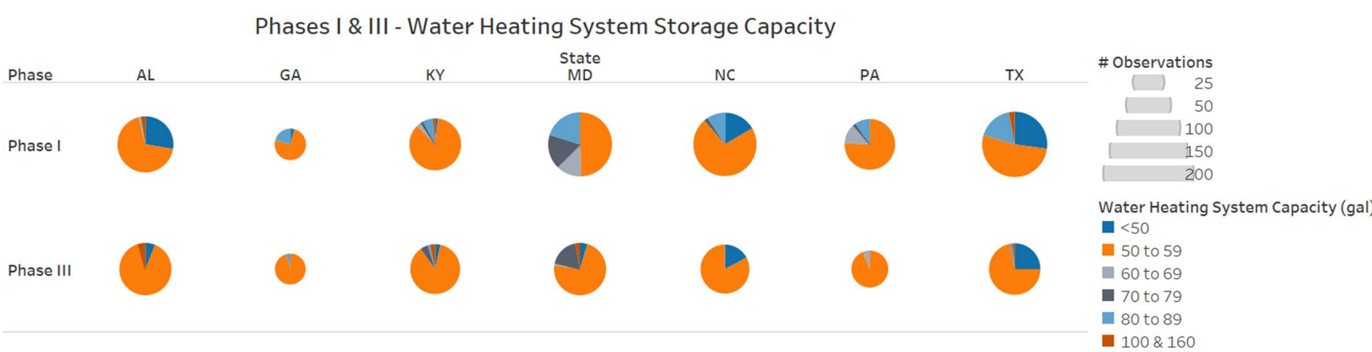

Figure D.14. Water Heating System Storage Capacity Distribution

D.1.5.4 Ventilation

Figure D.15 through Figure D.17 display ventilation and exhaust fan types and the mechanical manuals provided.

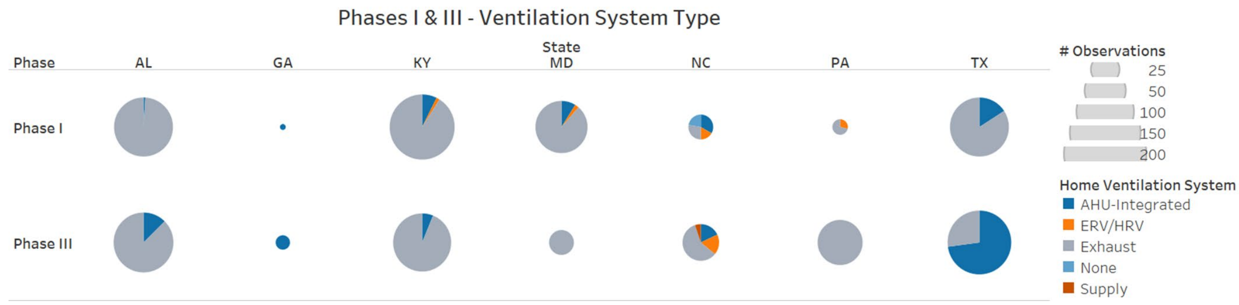

Figure D.15. Home Ventilation System Type

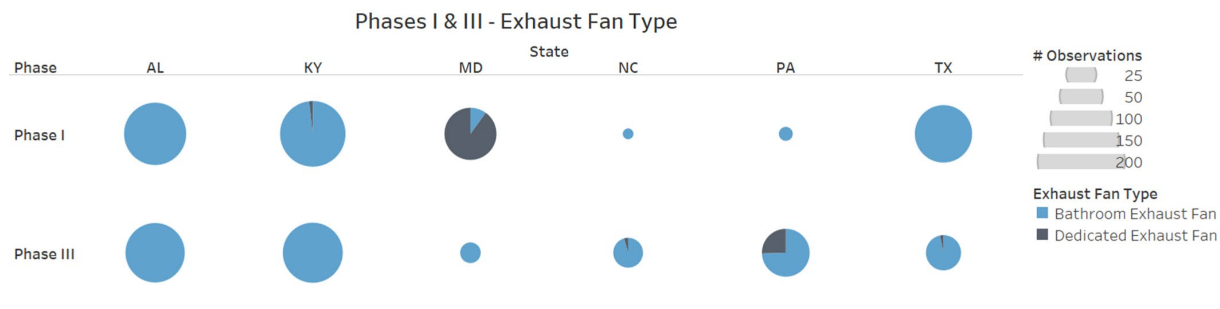

Figure D.16. Exhaust Fan Type

D.1.5.5 Other

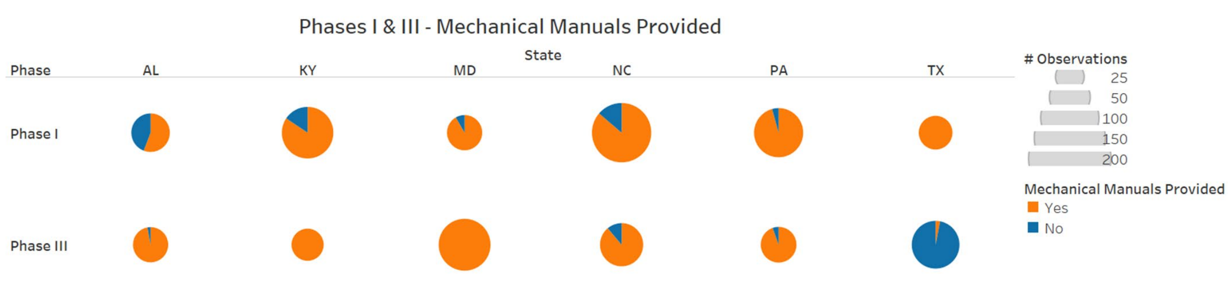

Figure D.17. Mechanical Manuals Provided

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