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Maryland Residential Energy Code Field Study: Final Report

September 2022

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

A research project in the state of Maryland identified opportunities to reduce homeowner utility bills in residential single-family new construction by increasing compliance with the state energy code. The study was comprised of three phases; (1) a **baseline study** to document typical practice and identify opportunities for improvement based on empirical data gathered from the field; (2) an **education and training** phase targeting the opportunities identified; and (3) a **post-study** to assess whether a reduction in average statewide energy use could be detected following the education and training phase. Together, this approach is intended to assist states in identifying technology trends and practices based on empirical data gathered in the field, evaluating how their codes are being implemented in practice, and targeting the most impactful and cost-effective opportunities for improvement based on their codes. The purpose of this report is to document findings and final results from the Maryland field study, including a summary of key trends observed in the field, their impact on energy efficiency, and whether the selected education and training activities resulted in a measurable change in statewide energy use. Public and private entities—state government agencies, utilities, and others—can also use this information to justify and catalyze investments in workforce education, training and related energy efficiency programs.

Background

The baseline field study (Phase I) was initiated in January 2015 and continued through June 2015. During this period, research teams visited 207 homes during various stages of construction, resulting in a substantial data set based on observations made directly in the field. Analysis of the Phase I data led to a better understanding of the energy features typically present in Maryland homes, and indicated over $1,500,000 in potential annual savings to homeowners in the state that could result from increased code compliance (Table ES.2).

Starting in April 2015 and continuing through April 2017, members of the Maryland field study team conducted targeted education and training activities (Phase II). Those activities included classroom and field training, outreach, circuit rider, and an Energy Code Coach hotline. More information on the specific education and training activities employed in the state is included in Section 2.5. Following the baseline study and the education and training phases, the research team conducted the post-study (Phase III), visiting an additional 185 homes across the state between April 2017 and April 2018. The results of this effort are presented Table ES.1 and discussed further in Section 3.0.

Methodology

The project team was led by the Maryland Energy Administration (MEA) with support from Newport Partners and Edge Energy. The team applied a methodology prescribed by the U.S. Department of Energy (DOE), which was based on collecting information for the energy code-required building components with the largest direct impact on energy consumption. These *key items* are a focal point of the study, and in turn drive the analysis and savings estimates[1]. As part of both the pre- and post-studies, the project team implemented customized sampling plans representative of new construction within the state, which were originally developed by Pacific Northwest National Laboratory (PNNL) and then vetted with stakeholders.

Following each data collection phase, PNNL conducted three stages of analysis on the resulting data set (Figure ES.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

[1] See Section 2.1

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.

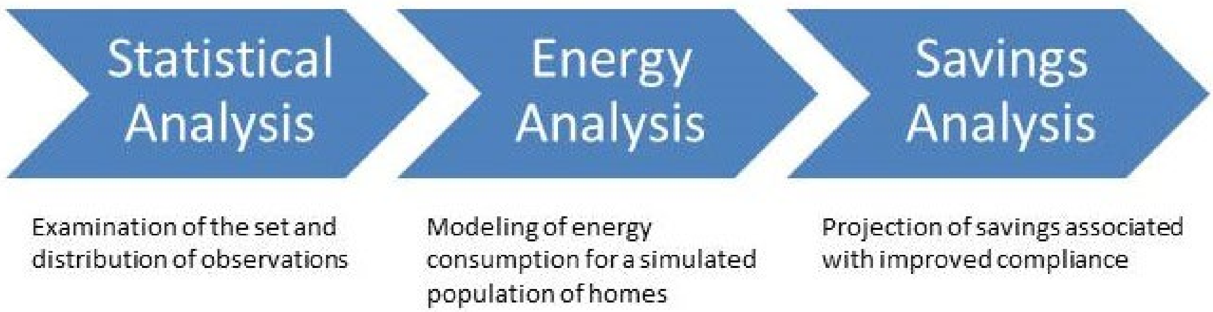

Figure ES.1. Stages of Analysis Applied in the Study

Success for the study is characterized by the following between Phase I and Phase III: 1) a measurable change in statewide energy use [a change in energy use intensity (EUI) of at least 1.25 kBtu/ft^2] and 2) a reduction in measure-level savings potential. To estimate average statewide energy consumption, field data was 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.

Results

As shown in Table ES.1, a measurable change was detected in statewide energy use between Phase I and Phase III. The Phase I analysis indicated homes used about 10.6 percent more energy than would be expected relative to homes built to the current state code. This percentage improved to 0.2 percent in Phase III, representing a change in EUI of approximately 9.8 percent (2.98 kBtu/ft^2) between Phases I and III.

Table ES.1. Average Modeled Energy Use Intensity in Maryland (kBtu/ft^2-yr)

Prescriptive EUI[1]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
27.56	30.49	+10.6%	27.51	-0.2%	-9.8%

Next, the field data was assessed from the perspective of individual energy efficiency measures, or the key items with the greatest potential for savings in the state, as presented in Table ES.2. These figures represent the potential annual savings associated with each measure as observed compared to a counterfactual scenario where all observations exactly met the prescriptive code requirement. The statistical trends were then extrapolated based on projected new construction across the 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

[1] Calculated based on the minimum prescriptive requirements of the state energy code.

measurable change was detected. In this case, improvement is achieved through a *reduction* in measure-level savings potential between Phases I and III.

Table ES.2. Estimated Annual Statewide Cost Savings Potential

Measure	Total Energy Cost Savings Potential ($)		$ Change	% Change
	Phase I	Phase III	Phase III vs. I	Phase III vs. I
Envelope Air Tightness	754,946	194,899	560,047	74.2%
Exterior Wall Insulation	401,479	73,498	327,981	81.2%
Duct Tightness	146,619	24,595	122,024	83.2%
Ceiling Insulation	44,366	10,307	34,059	23.2%
Lighting	195,378	8,115	187,263	76.8%
TOTAL	**$1,542,789**	**$311,414**	**$1,231,375**	**79.8%**

A reduction in energy cost savings potential (favorable) was achieved for all of the key item between Phase I and Phase III. This is an improvement of 80 percent and over $1,200,000 in annual cost savings achieved by Phase II targeted education and training activities. Therefore, Maryland meets the metrics for a successful project. However, even though results are good from an EUI standpoint, and savings were achieved, savings potential of over $300,000 (nearly 20% of original potential) still remains through targeted education and training.

This successful project provides the state with significant and quantified data that can be used to help direct future energy efficiency activities. DOE encourages states to conduct these types of studies every 3-5 years to validate state code implementation, quantify related benefits achieved, and identify ongoing opportunities to hone workforce education and training programs.

See Section 2.5 for additional information on the specific Phase II education and training activities conducted in Maryland. Detailed comparisons of key item distributions comparing Phase I and Phase III trends are in Section 3.1. For a complete table comparing Phase I and Phase III annual energy and cost savings potential across all three metrics and 5-, 10-, and 30-year savings potential projections see Appendix D. Although the focus of the study was on the key items, field data was collected that included home details (e.g., home size and number of stories) as well as many other code requirements (e.g., equipment efficiencies, labeling and sealing, etc.). Findings from this “other data” are provided in Appendix C.

Acknowledgments

This report was prepared by Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE) Building Energy Codes Program. The authors would like to thank Jeremy Williams at DOE for providing oversight and guidance throughout the project as well as his contributions to the content of this report.

The following members comprised the Maryland project team (with their affiliations during the project time period):

- Christopher Russell, *Maryland Energy Administration*
- David St. Jean, *Maryland Energy Administration*
- Valerie Holmes, *Maryland Energy Administration*
- Gary Boyer, *Edge Energy*
- Liza Bowles, *Newport Partners*
- Joe Nebbia, *Newport Partners*
- Sam Bowles, *Newport Partners*

Maryland Energy Administration (MEA)

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.

Newport Partners

Located in Davidsonville, MD, Newport Partners provides analytical and technical services to clients in both the private and public sectors. Established in 2002, the company maintains a balance of government and industry projects, including several university partners. Newport Partners' staff have backgrounds in engineering, law, planning, market research, and policy analysis, and they provide services ranging from full-service program development to meeting facilitation. More information on Newport Partners is available at www.newportpartnersllc.com.

Edge Energy

Edge Energy's technical capabilities include energy conservation measures, renewable energy projects, energy auditing, and general construction management. Established in 2006, they are a BPI-accredited "Gold Star" company. For further information on Edge Energy, visit http://www.edge-gogreen.com/.

Acronyms and Abbreviations

AC	air conditioning
ACH	air changes per hour
AFUE	annual fuel utilization efficiency
AHU	air handling unit
Btu	British thermal unit
cfm	cubic feet per minute
CFA	conditioned floor area
CO2e	carbon dioxide equivalent
CZ	climate zone
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EF	energy factor
EUI	energy use intensity
FOA	funding opportunity announcement
HSPF	heating season performance factor
ICC	International Code Council
IECC	International Energy Conservation Code
IIQ	insulation installation quality
kBtu	thousand British thermal units
MBIA	Maryland Building Industry Association
MD	Maryland
MEA	Maryland Energy Administration
MMBtu	million British thermal units
MT	metric ton
NA	not applicable
PNNL	Pacific Northwest National Laboratory
ROI	return on investment
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient

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1.0 Introduction

A three-phase research project in the state of Maryland investigated the energy code-related aspects of newly constructed, single family homes across the state. The study followed a prescribed methodology, with the objectives of generating an empirical data set based on observations made directly in the field, which could then be analyzed to identify compliance trends, their impact on statewide energy consumption, and calculate savings that could be achieved through increased code compliance. The next phase of the project included education and training activities targeting the specific energy efficiency measures and compliance trends identified in the first phase. Finally, an additional data collection phase and analysis were applied to determine if the education and training activities were effective in producing a measurable reduction in statewide energy use. The prescribed approach is intended to assist states in characterizing technology trends and practices, evaluating how their codes are being implemented in practice, and targeting the most impactful and cost-effective opportunities for improvement. In addition, the findings can help states, utilities and other industry stakeholders increase their return on investment (ROI) through compliance-improvement initiatives, and is intended to catalyze additional investments in workforce education, training and related energy efficiency programs.

The baseline field study (Phase I) was initiated in January 2015 and continued through June 2015. During this period, research teams visited 207 homes across the state during various stages of construction, resulting in a substantial data set based on observations made directly in the field. Analysis of the Phase I data led to a better understanding of the energy features typically present in Maryland homes, and indicated over $1,500,000 in potential annual savings to homeowners in the state that could result from increased code compliance.

Starting in April 2015 and continuing through April 2017, members of the Maryland field study team conducted targeted education and training activities (Phase II). Those activities included classroom and field training, outreach, circuit rider, and an Energy Code Coach hotline. More information on the specific education and training activities employed in the state is included in Section 2.5. Following the baseline study and the education and training phases, the research team conducted the post-study (Phase III), visiting an additional 185 homes across the state between April 2017 and April 2018. The results of this effort are presented in Section 3.0. At the time of the study, Maryland had the 2015 International Energy Conservation Code (IECC), which was adopted shortly before the start of Phase I, making it one of the first states to implement that model code and creating a unique opportunity for the study. The study methodology, data analysis and resulting findings are presented throughout this report.

1.1 Background

The data collected and analyzed for this report was in response to the U.S. Department of Energy (DOE) Funding Opportunity Announcement (FOA)[1] 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:

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

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

[1] Available at https://www.energycodes.gov/residential-energy-code-field-studies

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

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. [2,3] Hence, the importance of ensuring code-intended energy savings, so that homeowners realize the benefits of improved codes—something which happens only through high levels of compliance. More information on the original FOA and overall goals of the study is available on the DOE Building Energy Codes Program website.[4]

1.2 Project Team

The Maryland project was led by the Maryland Energy Administration (MEA), with support from Newport Partners, and field data collected by Edge Energy. The Pacific Northwest National Laboratory (PNNL) defined the methodology, conducted data analysis, and provided technical assistance to the project team. Funding and overall program direction was provided by the DOE Building Energy Codes Program as part of a broader initiative being conducted across several U.S. states. More information on the organizations comprising the project team is included in the Acknowledgements section of this report.

1.3 Stakeholder Interests

The project started with the formation of a stakeholder group comprised of interested and affected parties within the state. Following an initial kickoff meeting, the project team maintained active communication with the stakeholders throughout the course of the project. Stakeholders were sought from the following groups:

- Building officials
- Homebuilders
- Subcontractors
- Material supply distributors
- Government agencies
- Energy efficiency organizations
- Trade organizations
- Utilities
- Consumer interest groups
- Other important entities identified by the project team

A description of the stakeholders who participated in the project is included in Appendix A.

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[2] *National Energy and Cost Savings for New Single- and Multifamily Homes: A Comparison of the 2006, 2009, and 2012 Editions of the IECC.* https://www.energycodes.gov/sites/default/files/2020-06/NationalResidentialCostEffectiveness_2009_2012.pdf
[3] Available at https://www.energycodes.gov/status/residential
[4] Available at https://www.energycodes.gov/residential-energy-code-field-studies

Members of these groups are critical to the success of the project, as they hold important information about building design, construction and compliance trends within a given state or region, and which affect the research. For example, local building departments (i.e., building officials) typically maintain a database of homes under construction and are therefore key to the sampling process, control access to homes needed for site visits, administer and participate in education and training programs, or, as is typically the case with state government agencies, have oversight responsibilities for code adoption, implementation, and professional licensing. Utilities were also identified as a crucial stakeholder at the outset of the program. Many utilities have expressed an increasing interest in energy code investments and are looking at energy code compliance as a means to provide assistance. The field study was aimed specifically at providing a strong, empirically-based case for such utility investment—identifying key technology trends and quantifying the value of increased compliance, as is often required by state regulatory agencies (e.g., utility commissions) as a prerequisite to assigning value and attribution for programs contributing to state energy efficiency goals.

2.0 Methodology

2.1 Overview

The Maryland field study was based on a methodology developed and established by DOE to assist states in identifying technology trends, impacts and opportunities associated with increased energy code compliance. This methodology involves gathering field data on priority energy efficiency measures, as installed and observed in actual homes. In the subsequent analysis, trends and issues are identified, which are intended to inform workforce education and training initiatives and other compliance-improvement programs. The methodology empowers states through an empirically based assessment of trends, challenges and opportunities, and through an approach which can be adapted and replicated to track changes over time.

Highlights of the methodology:

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

PNNL identified the code-requirements (and associated energy efficiency measures) with the greatest direct impact on residential energy consumption. [1] These *key items* drive sampling, data analysis, and eventual savings projections:

1. Envelope tightness (ACH at 50 Pascals)
2. Windows (U-factor & SHGC)
3. Wall insulation (assembly U-factor)
4. Ceiling insulation (R-value)
5. Lighting (% high-efficacy)
6. Foundation insulation (R-value and assembly U-factor) [2]
7. Duct tightness (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 methodology.

[1] Based on the *mandatory* and *prescriptive* requirements of the International Energy Conservation Code (IECC).
[2] Floor insulation, basement wall insulation, crawlspace wall insulation, and slab insulation are combined into a single category of foundation insulation.

Success for the study is characterized by the following between Phase I and Phase III: 1) a measurable decrease in estimated statewide energy use [a change in energy use intensity (EUI) of at least 1.25 kBtu/ft^2] and 2) a reduction in measure-level savings potential.

The following sections describe how the methodology was implemented as part of the Maryland study, including sampling, data collection, and resulting data analysis. More information on the DOE data collection and analysis methodology is published separately from this report (DOE 2018) and is available on the DOE Building Energy Codes Program website.[3]

2.2 State Study

The prescribed methodology was customized to reflect circumstances unique to the state, such as state-level code requirements and regional construction practices. Customization also ensured that the results of the study would have credibility with stakeholders.

2.2.1 Sampling

PNNL developed statewide sampling plans statistically representative of recent construction activity within the state. The samples were apportioned to jurisdictions across the state in proportion to their average level of construction compared to the overall construction activity statewide. This approach is a proportional random sample, which PNNL based on the average of the three most recent years of Census Bureau permit data[4]. The sampling plan specified the number of key item observations required in each selected county (totaling 63 of each key item across the entire state). Maryland comprises a single climate zone (CZ4), therefore there is no differentiation of results by climate.

Statistical sampling methods were developed by PNNL and vetted by stakeholders within the state. Special considerations were discussed by stakeholders at a project kickoff meeting, such as state-specific construction practices and systematic differences across geographic boundaries. These considerations were taken into account and incorporated into the final statewide sample plans shown in Appendix B.

2.2.2 Data Collection

Following confirmation of the sample plans, the project team obtained lists of homes recently permitted for each of the sampled jurisdictions. These lists were then sorted using a random drawing process and applicable builders were contacted to gain site access. That information was then passed onto the data collection team who arranged a specific time for a site visit. As prescribed by the methodology, each home was visited only once to avoid any bias associated with multiple site visits. Only installed items directly observed by the field teams during site visits were recorded. If access was denied for a particular home on the list, field personnel moved onto the next home on the list.

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

[4] Available at http://censtats.census.gov/ (select the "Building Permits" data). The most recent data at the time was the 2013, 2014, and 2015 data.

2.2.2.1 Data Collection Form

The field teams relied on a data collection form customized to the mandatory and prescriptive requirements of the state energy code (unamended 2015 International Energy Conservation Code[5]). The final data collection form is available in spreadsheet format on the DOE Building Energy Codes Program website.[6] The form included all energy code requirements (i.e., not just the eight key items), as well as additional items required under the prescribed methodology. For example, the field teams were required to conduct a blower door test and duct tightness test on every home where such tests could be conducted, using RESNET[7] protocols.

Additional data was collected beyond the key items which was used during various stages of the analysis, or to supplement the overall study findings. For example, insulation installation quality impacts the energy-efficiency of insulation and was therefore used to modify that key item during the energy modeling and savings calculation. Equipment such as fuel type and efficiency rating, and basic home characteristics (e.g., foundation type) helped validate the prototype models applied during energy simulation. Other questions, such as whether the home participated in an above-code program, can assist in understanding whether other influencing factors are at play beyond the code requirements. In general, as much data was gathered as possible during a given site visit. However, data on the key items were prioritized given that a specified number was required for fulfillment of the sampling plan.

The data collected were the energy values observed, rather than the compliance status. For insulation, for example, the R-value was collected, for windows the U-factor. The alternative, such as was used in previous studies, simply stated whether an item did or did not comply (i.e., typically assessed as 'Yes', 'No', 'Not Applicable' or 'Not Observable'). The current approach provides an improved understanding of how compliance equates to energy consumption and gives more flexibility during analysis since the field data can be compared to any designated energy code or similar baseline.

2.2.2.2 Data Management and Availability

Once each data collection effort was complete, the project team conducted a thorough quality assurance review. This included an independent check of raw data compared to the information provided to PNNL for analysis, and helped to ensure completeness, accuracy and consistency across the inputs. Prior to submitting the data to PNNL, the team also removed all personally identifiable information, such as project site locations and contact information. The final dataset for each Phase is available in spreadsheet format on the DOE Building Energy Codes Program website.[8]

2.3 Data Analysis

All data analysis in the study was performed by PNNL, and was applied through three basic stages (for both Phase I and Phase III):

1. **Statistical Analysis:** Examination of the data set and distribution of observations for individual measures.

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[5] Based on stakeholder input, a question related to walls with partial structural sheathing was removed, as this assembly is not seen in Maryland (Section R402.2.7).

[6] Available at https://www.energycodes.gov/residential-energy-code-field-studies based on the forms typically used by the RES*check* compliance software.

[7] See https://www.resnet.us/wp-content/RESNET-Mortgage-Industry-National-HERS-Standards_3-8-17.pdf.

[8] Available at https://www.energycodes.gov/residential-energy-code-field-studies.

2. **Energy Analysis:** Modeling of energy consumption for a simulated population of homes.

3. **Savings Analysis:** Projection of savings associated with improved compliance.

The first stage identified compliance trends within the state based on what was 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 potential savings based on several metrics of interest to states and utilities—energy savings, consumer cost savings, and avoided carbon emissions associated with increased code compliance. This combination of methods and metrics provides valuable insight on challenges facing energy code implementation in the field, and are intended to inform future energy code education, training and outreach activities.

The following sections provide an overview of the analysis methods applied to the field study data, with the resulting state-level findings presented in Section 3.0, State Results.

2.3.1 Statistical Analysis

Standard statistical analysis was performed with distributions of each key item. This approach enables a better understanding of the range of data and provides insight on what energy-efficiency measures are most commonly installed in the field. It also allows for a comparison of installed values to the applicable code requirement, and for identification of any problem areas where potential for improvement exists. The graph below represents a sample key item distribution and is further explained in the following paragraph.

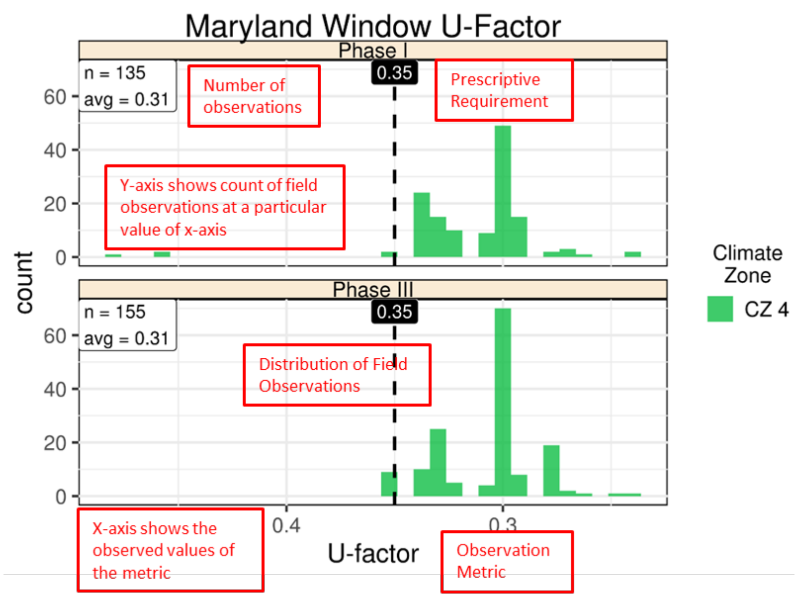

Figure 2.1. Sample Graph

Each graph is set up in a similar fashion, identifying the *state*, *climate zone*, and specific item being analyzed. The total *sample size* (n) is displayed in the top left or right corner of the graph, along with the distribution *average*. The *metric* associated with the item is measured along the horizontal axis (e.g., window U-factor is measured in Btu/ft2-hr-F), and a *count* of the number of observations is measured along the vertical axis. A vertical line is imposed on the graph representing the applicable code requirement (e.g., the prescriptive requirement in CZ4 is 0.35)—values to the right-hand side of this line represent observations which are *better than code*. Values to the left-hand side represent areas for improvement.

2.3.2 Energy Analysis

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 the 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.[9] Each of the 1,500 models was run multiple times, to represent each combination of heating systems and foundation types commonly found in the state. This resulted in upwards of 30,000 simulation runs for each climate zone within the state. An EUI was calculated for each simulation run and these results were then weighted by the frequency with which the heating system/foundation type combinations were observed in the field data. Average EUI 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.

Further specifics of the energy analysis are available in a supplemental methodology report (DOE 2018).[10]

2.3.3 Savings Analysis

To begin the third stage, each of the key items was examined individually to determine which had a significant number of observed values that did not meet the associated code requirement[11]. For these items, additional models were created to assess the savings potential, comparing what was observed in the field to a scenario of full compliance (i.e., where all worse-than-code observations for a particular item exactly met the corresponding code requirement).[12] The worse-than-code observations for the key item under consideration are used to create a second set of models (*as built*) that can be compared to the

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[9] *See* https://energyplus.net/

[10] Available at https://www.energycodes.gov/residential-energy-code-field-studies

[11] "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.

[12] Better-than-code items were not included in this analysis because the intent was to identify the maximum savings potential for each measure. The preceding energy analysis included both better-than-code and worse-than-code results, allowing them to offset each other.

baseline (*full compliance*) models. All other components were maintained at the corresponding prescriptive code value, allowing for the savings potential associated with a key item to be evaluated in isolation.

All variations of observed heating systems and foundation types were included, and annual electric, gas and total EUIs were extracted for each building. To calculate savings, the differences in energy use calculated for each case were weighted by the corresponding frequency of each observation to arrive at an average energy savings potential. Potential energy savings were further weighted using construction starts to obtain the average statewide energy savings potential. State-specific construction volumes and fuel prices were used to calculate the maximum energy savings potential for the state in terms of *energy* (MMBtu), *energy cost* ($), and *avoided carbon emissions* (MT CO2e).

Note that this approach results in the maximum theoretical 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 is very small and could safely be ignored without changing the basic conclusions of the analysis.

Another aspect of savings potential that is not included is the presence of better-than-code items. While it is indeed possible that one better-than-code component may offset the energy lost due to another worse-than-code component, the collected data does not allow for the assessment of paired observations for a given home. Additionally, the analysis identifies the maximum theoretical savings potential for each measure; therefore, credit for better-than-code measures is not accounted for in the savings analysis.

An issue that can impact both the EUI and savings potential analysis is the presence of abnormal values. One of the lessons learned during previous field studies is that there are occasional data outliers, observations that seem much higher or lower than expected, such as higher than anticipated total duct tightness rates or ceiling insulation values of R-0. Such data outliers may be the result of errors (by the builder or by the field team) or they may simply be extreme but valid data points. It can be difficult to differentiate between these two cases given the limited information available to and provided by field data collectors.

Under ideal circumstances, project teams would identify outliers at the time of data collection during field visits, and employ procedures to flag and evaluate atypical conditions, data points or observations. During the course of the data QA/QC process, remaining outliers were discussed with the project teams and, where applicable and appropriate, data were modified prior to analysis. Given that this was a research study, and in many cases valid extremes do exist in the field, it was decided to retain all other data outliers in the analysis. This allows a given team or state to understand the presence of, and related impacts, of valid outliers in their data set. The impact of this decision is that there may be some "extreme" data points that appear in the key item plots and impact the measure level savings and EUI results, which have been deliberately retained in the data set. In addition, the field 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 in the field.

2.4 Limitations

The following sections address limitations of the project, some of which are inherent to the methodology itself, and other issues as identified in the field.

2.4.1 Applicability of Results

An inherent limitation of the study design is that the results (key item distributions, EUI, and measure-level savings) can be considered statistically significant only at the state level and not at the county or other sub-unit 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 are included and available but should not be considered statistically representative.

2.4.2 Definition and Determination of Compliance

The field study protocol is based upon 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 visit to know whether all code requirements have been met. For example, homes observed during the earlier stages of construction often lack key features affecting energy performance (e.g., walls with insulation), and in the later stages many of these items may be covered and therefore unobservable. To gather all the data required in the sampling plan, field teams therefore needed to visit homes in various stages of construction. The analytical implications of this are described above in Section 2.3.2. This approach gives a robust representation of measure compliance across the state.

2.4.3 Sampling Substitutions

As is often the case with field-based research, substitutions to the state sampling plans were sometimes needed to fulfill the complete data set. If the required number of observations in a jurisdiction could not be met because of a lack of access to homes or an insufficient number of homes (as can be the case in rural areas), substitute jurisdictions were selected by the project team. In all cases, the alternative selection was comparable to the original in terms of characteristics such as the level of construction activity and general demographics. More information on the sampling plans and any state-specific substitutions is discussed in Appendix B.

2.4.4 Site Access

Site access was purely voluntary, and data was 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 inherent due to the voluntary nature of the study. The impacts of this bias on the overall results are not known.

2.4.5 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 tightness 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.

2.4.6 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 team agreed that this was a reasonable approach. The overall data set 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.

2.5 Phase II Targeted Education and Training

The intent of the overall study was to identify the highest-impact, biggest "bang-for-the-buck" energy efficiency measures (key items), and then assess whether average statewide energy use could be reduced by focusing on those measures. Phase II involved education and training targeting those measures. For example, if wall insulation, lighting, and envelope air tightness all exhibited significant savings potential following Phase I analysis, those measures became the focal point for Phase II. By focusing on key measures, the methodology helps ensure maximum ROI for education and training activities and other compliance improvement programs. Many states have some form of ongoing training and identifying and focusing on the key items helps those programs maximize their investment.

Given their state-specific knowledge, the project team and stakeholders selected the education and training activities to be used that were anticipated to have the largest impact in the state. Activities were conducted throughout the entire state.

For any given state, a variety of activities was used, ranging from more traditional activities such as classroom-based training, to more advanced approaches, such as web-based and onsite education, as well as circuit rider[13] programs. All activities were designed to coordinate with, and complement, any related or ongoing training efforts in the state (such as those conducted by local utilities, state governments, or national programs such as EPA EnergyStar). The level of funding and effort for Phase II activities varied by state.

For Maryland, specific Phase II activities included (Newport Partners 2018):

- Circuit rider: The circuit rider was a focus of the Phase II intervention activities and provided support to individual stakeholders (e.g., code officials and builders) that was supplemented with in-person trainings, outreach, and an Energy Code Coach hotline. Upon request to discuss energy codes and related issues, the circuit rider met with individual and groups of code officials and builders at their businesses or construction sites. There were 18 circuit rider events, with a total of 575 attendees.
- In-person training: There were 46 classroom and field training events that reached 905 participants. These events had audience-specific curricula and most were held in a classroom environment. Successful field-based training requires a willing builder and an ability to use a building under construction. The field-based training was usually limited to specific issues and with a limited number of participants. The team found it to be a very effective delivery tool with knowledgeable

[13] 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, expertise and training on compliance best practices).

trainers and willing builders. The team recommends utilizing field-based training selectively and notes the instructor is key and must be able to train without notes and engage participants. In all cases, the team feels the training is greatly enhanced when instructors are knowledgeable of not only the energy code but construction practices as well.

- Energy Code Coach assistance hotline: This service included a phone line that stakeholders could call with questions, email address for those that preferred to email questions and issues, and an on-site service if that was necessary to resolve questions/issues with a builder or contractor. The hotline responded to 150 requests for assistance.
- Other: Additional resources that were developed to support the project include: newsletters, fact sheets and flyers, inspection checklists, code coach "cheat sheets" highlighting code requirements, and architectural drawings showing necessary energy code details. Fact sheet topics include lighting and sill plates[14]. "Cheat sheet" topics include: lighting requirements, building thermal envelope air tightness requirements, duct tightness testing requirements, Energy Rating Index compliance path, and prescriptive insulation and window requirements.[15] In addition, several training PowerPoint presentations were created that included illustrations of code requirements and issues observed in the field. For code officials, a set of mock plans was developed and used in training sessions on plan review. A project website area was maintained to make resources available to stakeholders.

2.6 Phase III Field Study and Analysis

In Phase III, the data collection undertaken in Phase I was repeated, starting with a new sample plan. Once the field data was collected, PNNL analyzed the data in the same way as in Phase I (described in Section 2.3) with the following exceptions that were held constant between Phase I and Phase III:

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
6. For states in which the baseline energy code changed and for which PNNL compared the observations to two codes, PNNL only compared the observations to the newest code in Phase III.

All of these changes were made to minimize 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. Maryland has two climate zones, but Climate Zone 5 has very little construction and was therefore omitted from the sample, and the code did not change during the course of the study, so items #2, 5, and 6 above were not applicable.

[14] Fact sheets available at http://newportpartnersllc.com/projects/residential_energy_efficiency.html#coach
[15] "Cheat sheets" available at http://newportpartnersllc.com/projects/residential_energy_efficiency.html#coach

3.0 State Results

3.1 Field Observations

3.1.1 Key Items

The field study and underlying methodology are driven by key items that have a significant direct impact on residential energy efficiency. The graphs presented in this section represent the key item results for the state based on the measures observed in the field. (See Section 2.3.1 for a sample graph and explanation of how they should be interpreted.) Note that these key items are also the basis of the results presented in the subsequent *energy* and *savings* stages of analysis.

The following key items were found applicable within the state:

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

Between Phase I and Phase III, there were three main foundation types observed in Maryland: conditioned basements, floors, and slabs. It should be noted that in Phase III, there were only a minimal number of observations of floors (two) and slabs (six).

[1] Although there are no SHGC requirements in Climate Zone 4, this section includes the distribution of SHGC observations for reference.

3.1.1.1 Envelope Tightness

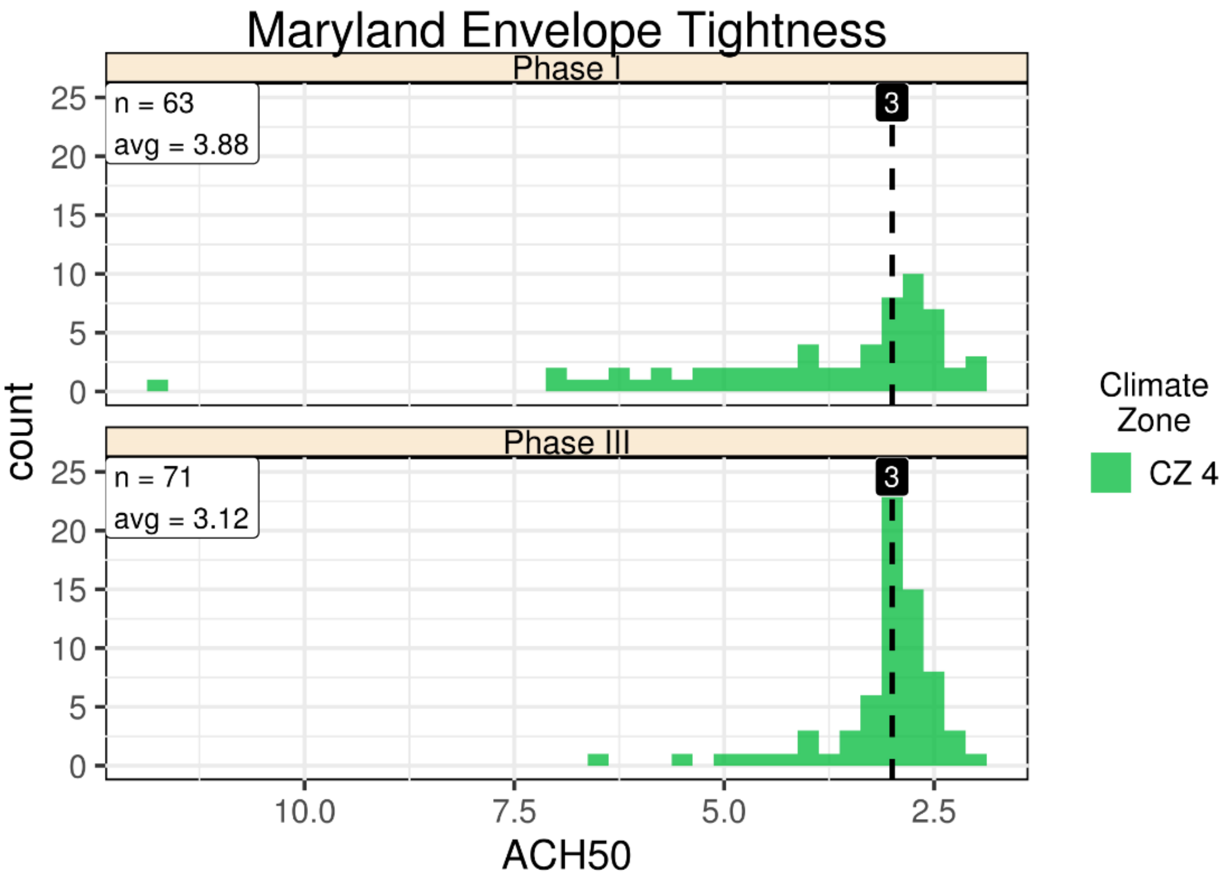

Figure 3.1. Comparison of Phase I and Phase III Envelope Tightness for Maryland

Table 3.1. Maryland Envelope Tightness in Phase I and Phase III

Envelope Tightness (ACH50)	MD Phase I	MD Phase III
Requirement	3 ACH50	3 ACH50
Observations		
Number	63	71
Range	11.80 to 1.92	6.5 to 2.05
Average	3.9	3.1
Compliance Rate	34 of 63 (54%)	46 of 71 (65%)

- **Interpretations**
  - In Phase I, reductions in envelope air tightness represented an area for improvement in the state and was a focus of Phase II education and training activities. The project team reported that implementation of the ACH requirement had been problematic in townhomes. In some jurisdictions (but not all), code officials allowed a “guarded” blower door test to be performed in townhomes, which requires access to multiple units. For the purposes of this study, field personnel performed a typical (single) blower door test for each individual townhome, often with no knowledge of how the test had been performed previously on a given unit (e.g., for purposes of

demonstrating code compliance). It is possible that certain townhomes may have met the air tightness requirement through a "guarded" blower door test but failed under the single blower door test performed by the field team. This may be a significant issue in Maryland, where approximately half of all new construction is townhomes.

– There was some improvement after the Phase II activities (as measured in Phase III). However, savings potential remains, and envelope air tightness should remain a focus of future education and training activities.

3.1.1.2 Window SHGC

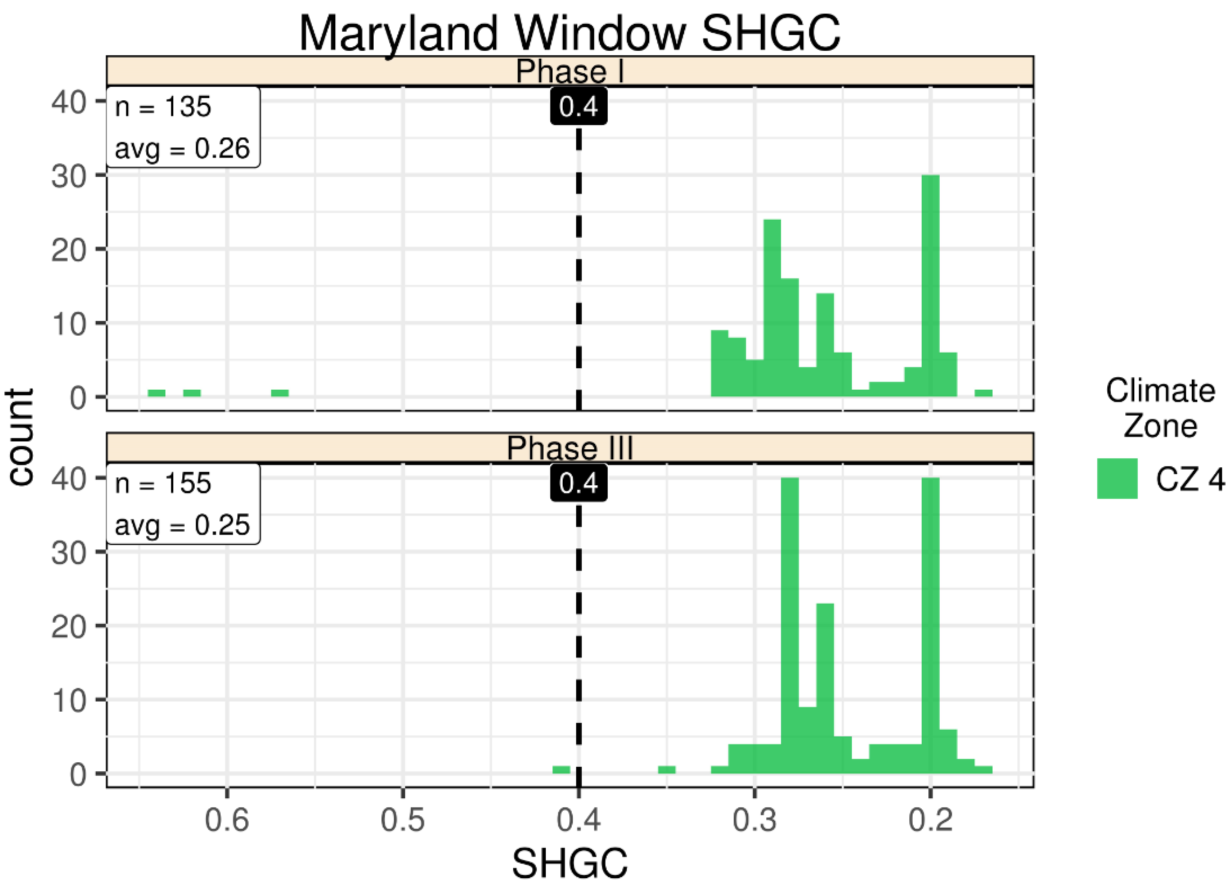

Figure 3.2. Comparison of Phase I and Phase III Window SHGC for Maryland

Table 3.2. Maryland Window SHGC in Phase I and Phase III

Window SHGC	MD Phase I	MD Phase III
Requirement	NA	NA
Observations		
Number	135	155
Range	0.64 to 0.17	0.41 to 0.17
Average	0.26	0.25
Compliance Rate	NA	NA

- **Interpretations:**
  - Although there is no SHGC requirement in Climate Zone 4, SHGC values were similar across both Phase I and Phase III and nearly met the prescriptive requirement for Climate Zones 1-3 in both phases.

3.1.1.3 Window U-Factor

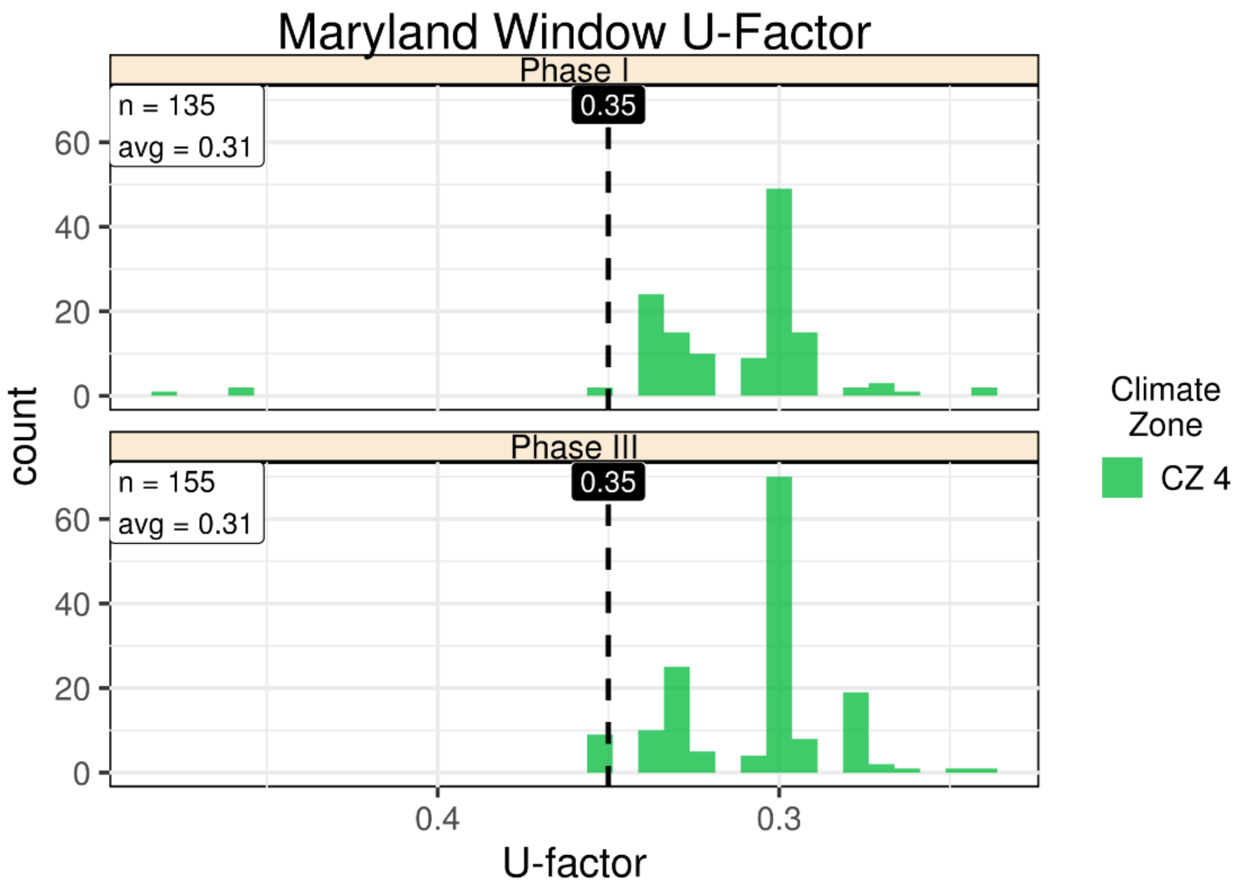

Figure 3.3. Comparison of Phase I and Phase III Window U-Factors for Maryland

Table 3.3. Maryland Window U-Factors in Phase I and Phase III

Window U	MD Phase I	MD Phase III
Requirement	0.35	0.35
Observations		
Number	135	155
Range	0.48 to 0.24	0.35 to 0.24
Average	0.31	0.31
Compliance Rate	132 of 135 (98%)	155 of 155 (100%)

- **Interpretations:**
  - There is a high rate of compliance for fenestration products across both Phase I and Phase III.

– This represents one of the most significant findings of the field study, with nearly all of the observations at or above the code requirement.

3.1.1.4 Wall Insulation

The code allows for two prescriptive options for wall insulation (R-20 or R-13+5 continuous). The energy performance of a wall insulation system is determined both by the R-value of the insulation installed and the quality of the installation. Given the large number of possible combinations of compliance options and installation qualities, the results are presented as U-factors which allow all relevant aspects to be considered in one metric.

Maryland had a high number of frame walls containing both cavity and continuous insulation. In Phase I, there were 24 observations of frame wall continuous insulation, and Phase III had 36 observations of continuous insulation. Given this, presenting a graph of only cavity insulation R-values would provide a distorted picture. Figure 3.4 and Table 3.5 provide a more complete picture and also address insulation installation quality (IIQ).

It should also be noted that there were four mass walls observed in Phase I, but no mass walls in Phase III. These are not shown in the wall R-value or wall U-factor figures and tables. The R-values of the four mass walls are either 13 or 15 (split evenly). Given the relatively small number of mass walls and the fact they only occur in Phase I, mass walls are not included in the report.

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 and applied as a *modifier* in the analyses for applicable key items (i.e., wall insulation, ceiling insulation, and foundation insulation). Teams followed the RESNET[2] assessment protocol for cavity insulation which has three grades; Grade I being the best quality installation and Grade III being the worst.

Table 3.4 shows the number and percentage of IIQ observations by grade for above grade wall insulation for Phase I and Phase III. The table illustrates that above grade wall IIQ improved significantly from Phase I to Phase III, with all Grade I observations.

Table 3.4. Comparison of Phase I and Phase III Above Grade Wall IIQ for Maryland

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Above Grade Wall Observations	33 / 69	21 / 0	2 / 0	**56 / 69**
Above Grade Percentages	59% / 100%	38% / 0%	2% / 0%	**100% / 100%**

Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.4. In the graph, observations are binned for clearer presentation based on the most commonly observed combinations.

[2] 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.

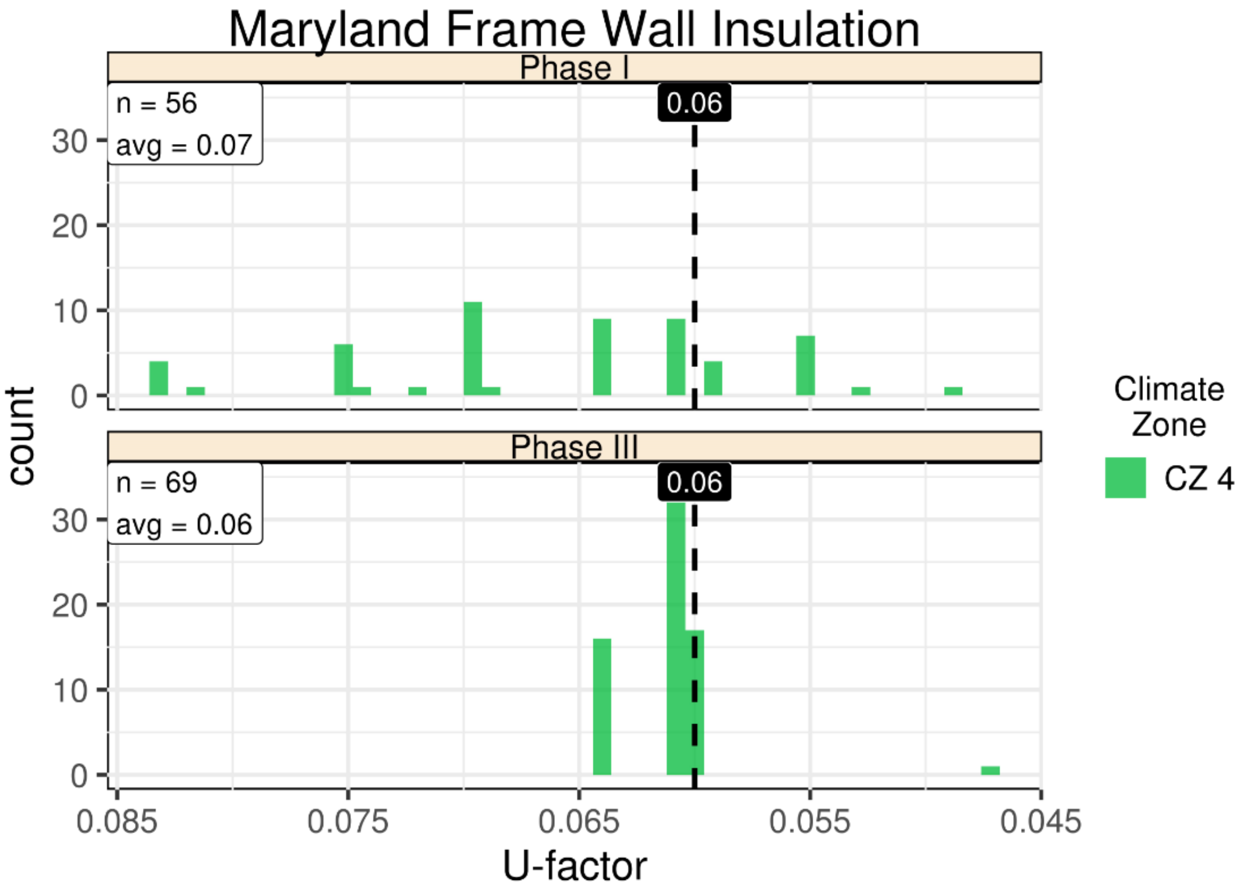

Figure 3.4. Comparison of Phase I and Phase III Wall U-Factors for Maryland

Table 3.5. Maryland Wall U-Factors in Phase I and Phase III

Wall U		MD Phase I	MD Phase III
Requirement		U-0.060	U-0.060
Observations			
	Number	56	69
	Range	U-0.083 to U-0.048	U-0.064 to U-0.047
	Average	U-0.066	U-0.061
	Compliance Rate	14 of 56 (25%)	18 of 69 (26%)

- **Interpretations:**
  - In Phase I, a significant number of homes were observed to be using R-19 cavity-only insulation (13 observations) instead of the required R-20. This was reported by the project team as a common misconception in the marketplace, where installers use an attic batt, which is too wide for the cavity, and incorrectly assume the closest thing to R-20 complies. While the energy impact of using R-19 (vs. R-20) is relatively minor, it does not officially meet the prescriptive requirement. There were also several assemblies observed with R-13 or R-15 without any continuous insulation

at all[3]. Interestingly, none of the cavity observations occurred at either of the prescriptive values (R-13+R-5 or R-20).There are a large number of observations (18) of R-15+3 cavity, which does not meet the prescriptive (R-13 cavity + R-5 continuous) requirement, and does not yield the same overall assembly performance. Insight from the project team indicates a significant amount of confusion surrounding wall insulation, particularly involving combinations of cavity and continuous insulation and in terms of how assembly performance should be calculated.

In Phase III, there was a minor improvement in both the average U-factor and compliance rate, but the average is still slightly over the code requirement. The range of observations is much tighter, with the worst observations being mostly eliminated. However, it is also striking that the number of observations of U-factor "better than code" was also greatly reduced. The reason for the relative tightness of the distribution of the Phase III U-factors compared to Phase I U-factors is unknown.

IIQ has a significant effect on overall wall assembly performance. While the majority of observations were noted as Grade I, there were several instances observed as Grade II or III[4] in Phase I. IIQ improved in Phase III with all observations noted as Grade I.

Note the fact that many of the Phase III wall U-factors are just slightly non-compliant could also indicate the use of envelope tradeoffs. Given that Phase III ceiling observations are mostly "at code" while Phase III window U-factors are almost entirely better than code, the possibility of a window and wall tradeoff is fairly high.

3.1.1.5 Ceiling Insulation

Figure 3.5 represents the observed R-values for Maryland ceilings.

[3] These observations were reviewed in an attempt to verify that additional insulation was indeed absent. Due to the timing of the single site visit, it is plausible that the data collection occurred before continuous insulation was installed. However, this remains unclear, as the data associated with these specific instances suggests that no continuous insulation was present. As this applies to only a minority of observations (5), it is not considered to significantly affect the analysis.

[4] Based on the RESNET protocol for insulation grading: https://www.resnet.us/wp-content/RESNET-Mortgage-Industry-National-HERS-Standards_3-8-17.pdf

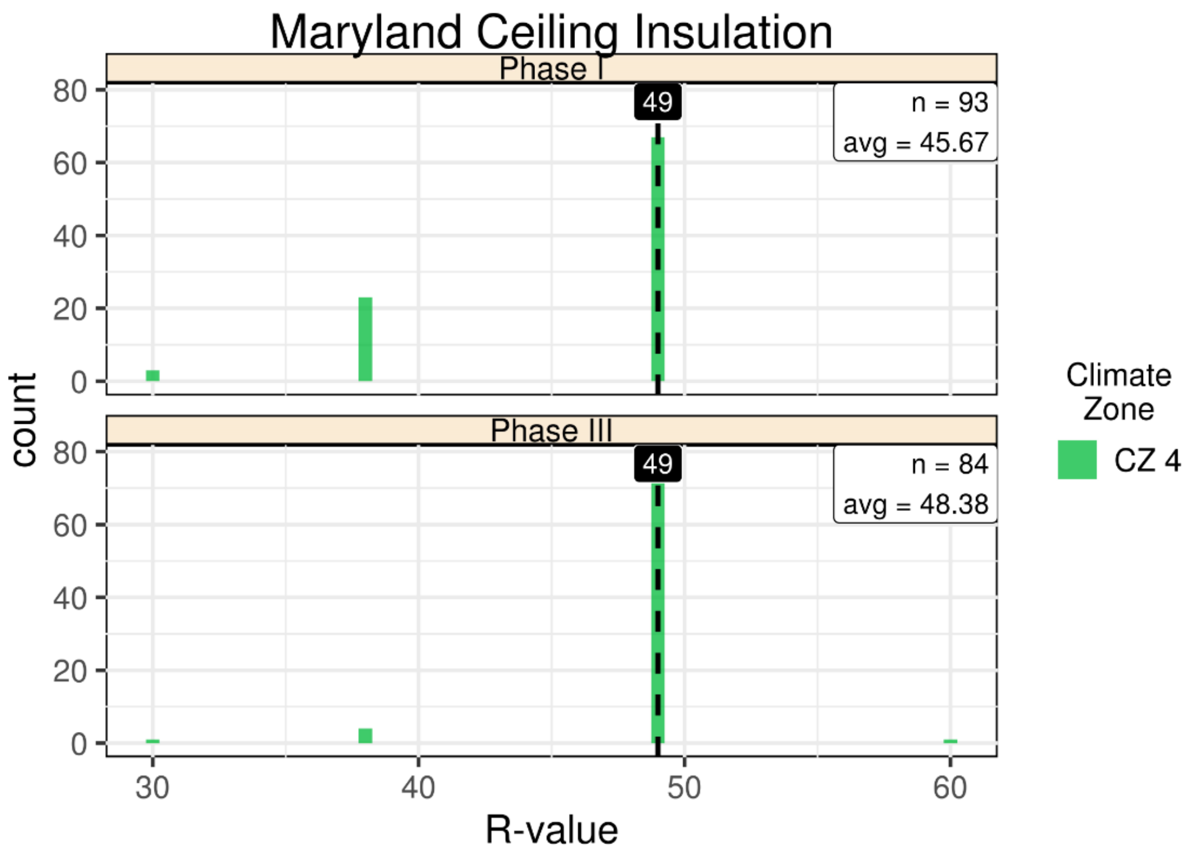

Figure 3.5. Comparison of Phase I and Phase III Ceiling R-Values for Maryland

Table 3.6. Maryland Ceiling R-Values in Phase I and Phase III

Ceiling R		MD Phase I	MD Phase III
Requirement		R-49	R-49
Observations			
	Number	93	84
	Range	R-30 to R-49	R-30 to R-60
	Average	R-45	R-48
	Compliance Rate	67 or 93 (72%)	79 of 84 (94%)

Table 3.7 shows the number and percentage of IIQ observations by grade for roof cavity insulation for Phase I and Phase III. The table illustrates that roof cavity IIQ improved from Phase I to Phase III, with all of the Phase III observations being Grade I.

Table 3.7. Comparison of Phase I and Phase III Roof IIQ for Maryland

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Roof Cavity Observations	86 / 84	7 / 0	0 /0	**93 / 84**
Roof Cavity Percentages	92% / 100%	8% / 0%	0% / 0%	**100% / 100%**

Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.6.

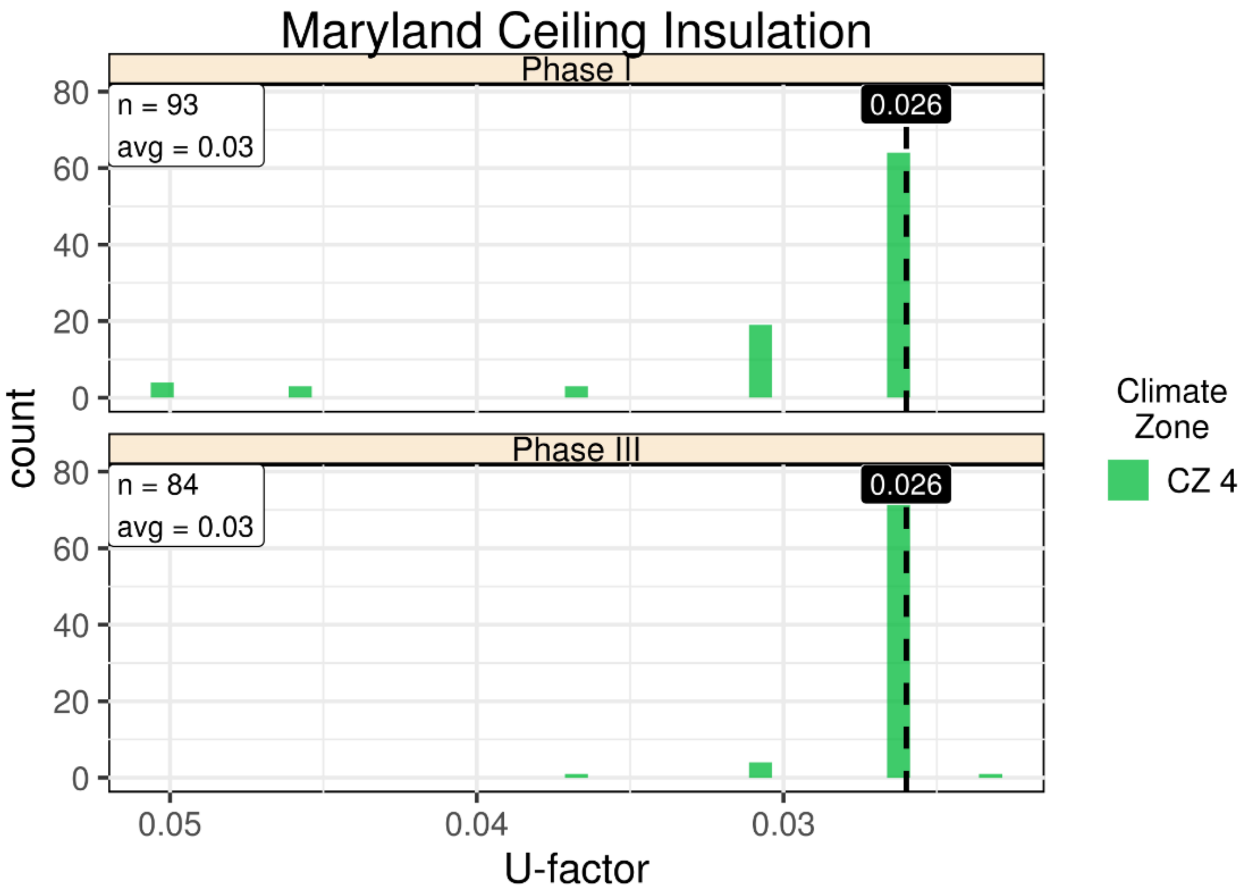

Figure 3.6. Comparison of Phase I and Phase III Ceiling U-Factors for Maryland

Table 3.8. Maryland Ceiling U-Factors in Phase I and Phase III

Ceiling U	MD Phase I	MD Phase III
Requirement	U-0.026	U-0.026
Observations		
Number	93	84
Range	U-0.050 to U-0.026	U-0.036 to U-0.023
Average	U-0.029	U-0.026
Compliance Rate	64 of 93 (69%)	79 of 84 (94%)

- **Interpretations:**
  - The majority of R-value observations met the code requirement exactly in both Phase I and Phase III.
  - Overall, neither the amount of ceiling insulation nor IIQ appear to currently be issues in the state.

3.1.1.6 Lighting

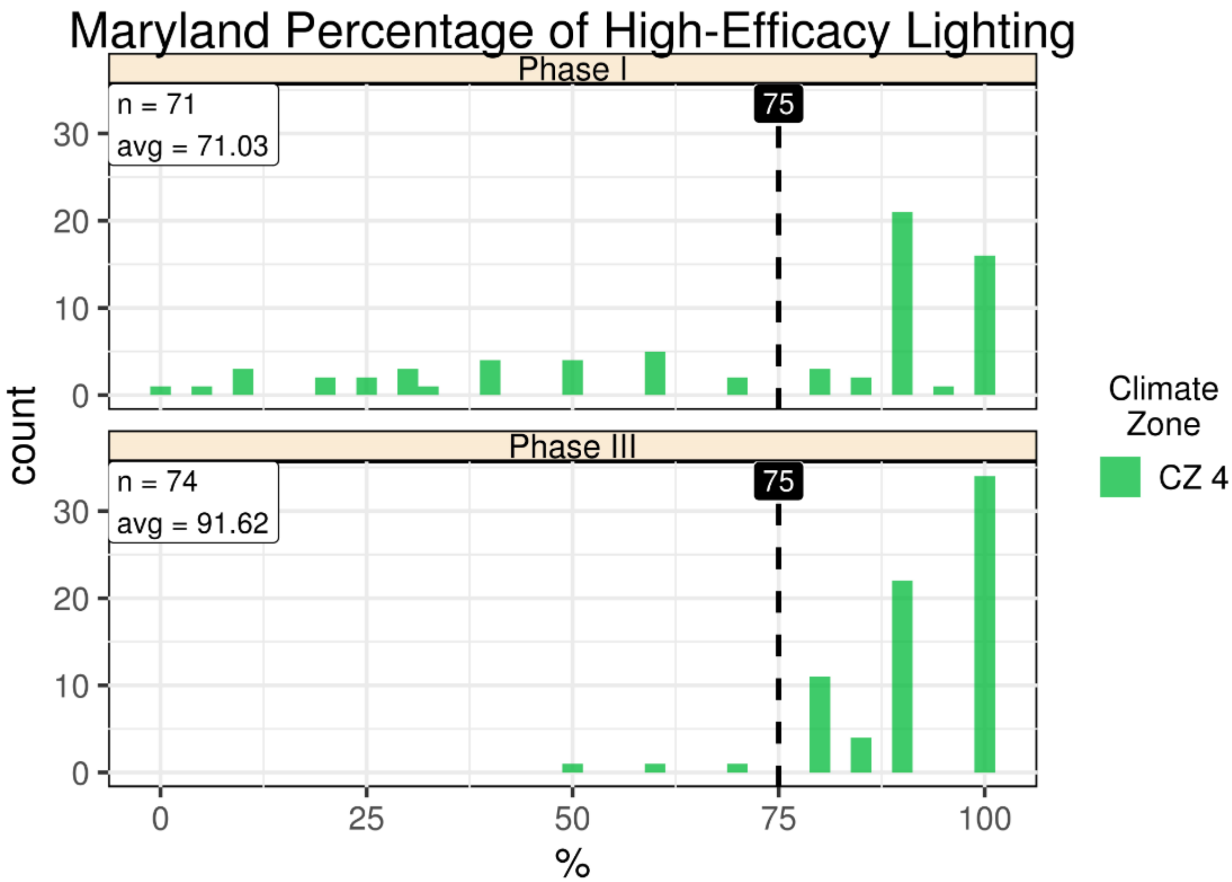

Figure 3.7. Comparison of Phase I and Phase III High-Efficacy Lighting Percentages for Maryland

Table 3.9. Maryland High-Efficacy Lighting in Phase I and Phase III

Lighting	MD Phase I	MD Phase III
Requirement	75%	75%
Observations		
Number	71	74
Range	0 to 100	50 to 100
Average	71	92
Compliance Rate	43 of 71 (61%)	71 of 74 (96%)

- **Interpretations:**
  - A little more than half of the field observations were observed to meet the requirement in Phase I; a much lower number than expected. This represented an area of significant savings potential and was a focus of Phase II education and training activities. In an attempt to better understand these results, the project team conducted additional market research to better understand the factors contributing to non-compliance with the lighting requirements. The team reported the following examples:

- ○ A general lack of understanding of what constitutes a high-efficacy lamp.
- ○ Common misconceptions associated with particular bulb types (e.g., confusion on halogen lamps with comments like, "All of our lighting is energy efficient. We use 100% halogens.")
- ○ Lighting is not clearly specified on plans and the electrician may or may not be familiar with energy code requirements.

– There was a significant improvement in Phase III with nearly all of the observations meeting or exceeding the requirement.

Lighting was a focal point of Phase II education and training activities, and the project team took lighting demonstrations to trainings, produced a widely-distributed fact sheet on lighting, and sent a newsletter highlighting the requirement to builders and code officials. The team feels that since this is a requirement that is easy to explain and compliance is straightforward, once builders and code officials were made aware, compliance went up quickly.

3.1.1.7 Foundation Assemblies

There were three predominant foundation types observed in Maryland: conditioned basements, floors[5], and slabs. Two graphs are shown for basement walls and floors, insulation (R-value) and binned assembly (U-factor). The R-value graphs show the insulation R-values observed. The binned U-factor graphs indicate the U-factor of the assembly, including both cavity and continuous insulation layers, framing, and considering IIQ, as observed in the field. The U-factors are binned to reduce the number of bars in the chart as individual U-factor observations may be only slightly different. For slabs, only an R-value graph is shown.

While initially combined into a single key item (i.e., foundation assemblies[6]), the variety of observed foundation types is disaggregated in this section, as described above. This approach helps to portray the combinations of cavity and continuous insulation employed across each foundation type, which was anticipated to be of value for energy code training programs. From a savings perspective, results are calculated for both the aggregated perspective individual foundation types (presented later in Section 3.3), however; only the aggregated observations should be considered statistically representative at the statewide level.

[5] There were 57 observations of floor insulation in Phase I but only two observations in Phase III.

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

Basement Walls

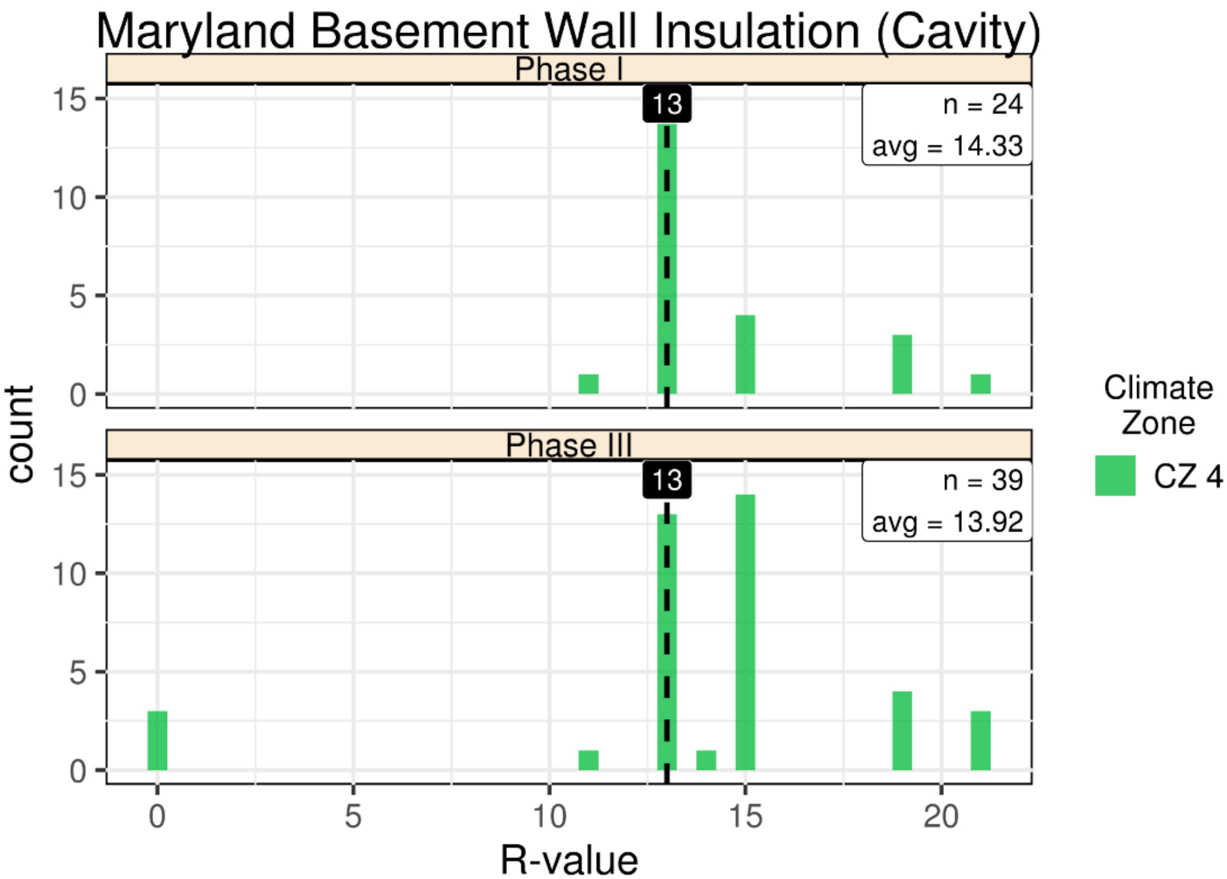

Figure 3.8. Comparison of Phase I and Phase III Basement Wall Cavity R-Values for Maryland[7]

Table 3.10. Maryland Basement Wall R-Values (Cavity) in Phase I and Phase III

Basement Cavity	MD Phase I	MD Phase III
Requirement	R-13	R-13
Observations		
Number	24	39
Range	R-11 to R-21	R-0 to R-21
Average	R-14.33	R-13.92[8]
Compliance Rate	23 of 24 (96%)	35 of 39 (90%)

[7] Note that Phase III Basement Wall Insulation (Cavity) has three observations of R-0 collected by the Field Team. These observations are all associated with R-11 Basement Wall Insulation (Continuous) discussed in the next figure and table. These R-0 observations are combined with R-11 observations in Figure 3.11 and Table 3.14. The U-factor results are a much better indicator of the compliance of basement walls than either the cavity or continuous insulation results

[8] Without the three R-0 observations, the average R-value for cavity insulation would be R-15.08.

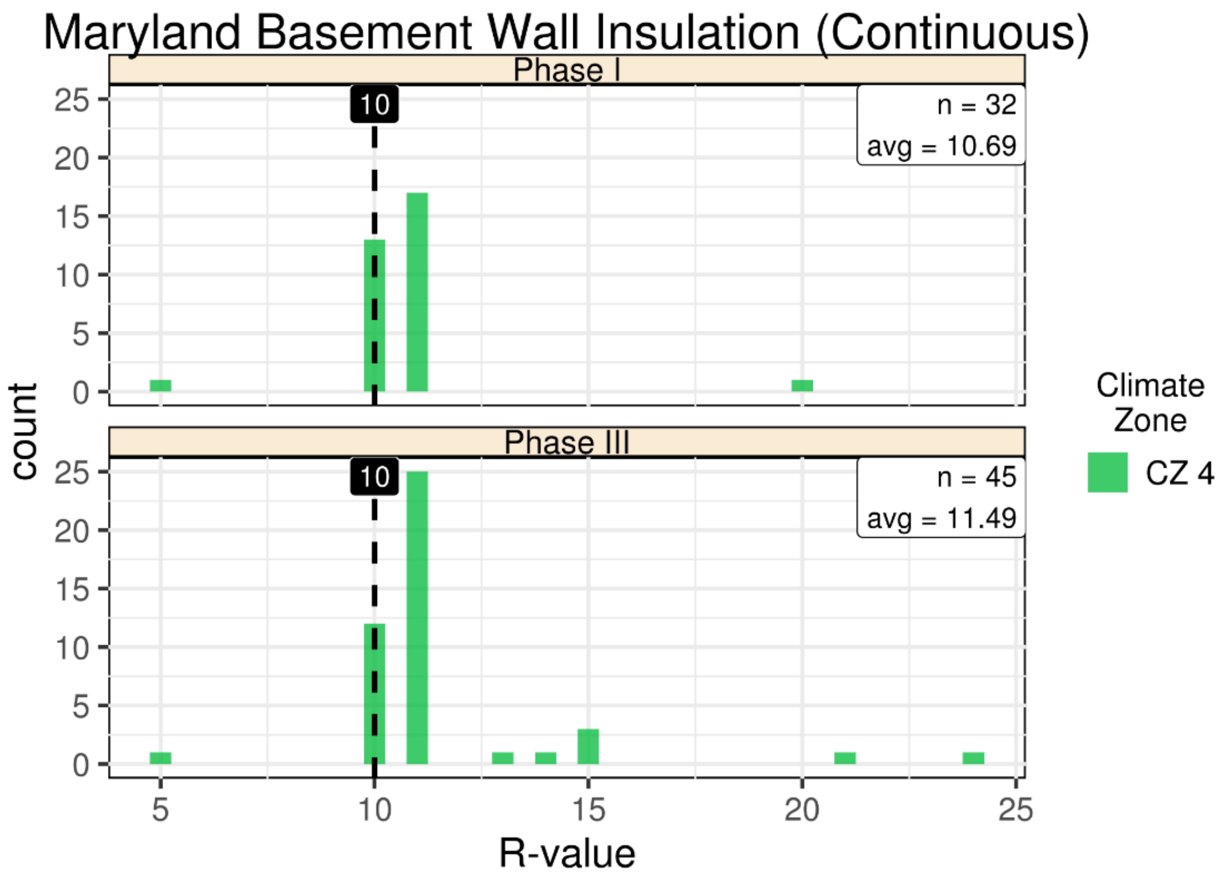

Figure 3.9. Comparison of Phase I and Phase III Basement Wall Continuous R-Values for Maryland

Table 3.11. Maryland Basement Wall R-Values (Continuous) in Phase I and Phase III

Basement Continuous	**MD Phase I**	**MD Phase III**
Requirement	R-10	R-10
Observations		
Number	32	45
Range	R-5 to R-20	R-5 to R-24
Average	R-10.69	R-11.49
Compliance Rate	31 of 32 (97%)	44 of 45 (98%)

Table 3.12 shows the number and percentage of IIQ observations by grade for basement wall insulation for Phase I and Phase III. Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.10.

Table 3.12. Basement Wall IIQ Comparison between Phase I and Phase III for Maryland

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Basement Wall Observations	46 / 39	6 / 0	2 /0	**54 /39**
Basement Wall Percentages	85% / 100%	11% / 0%	4% / 0%	**100% / 100%**

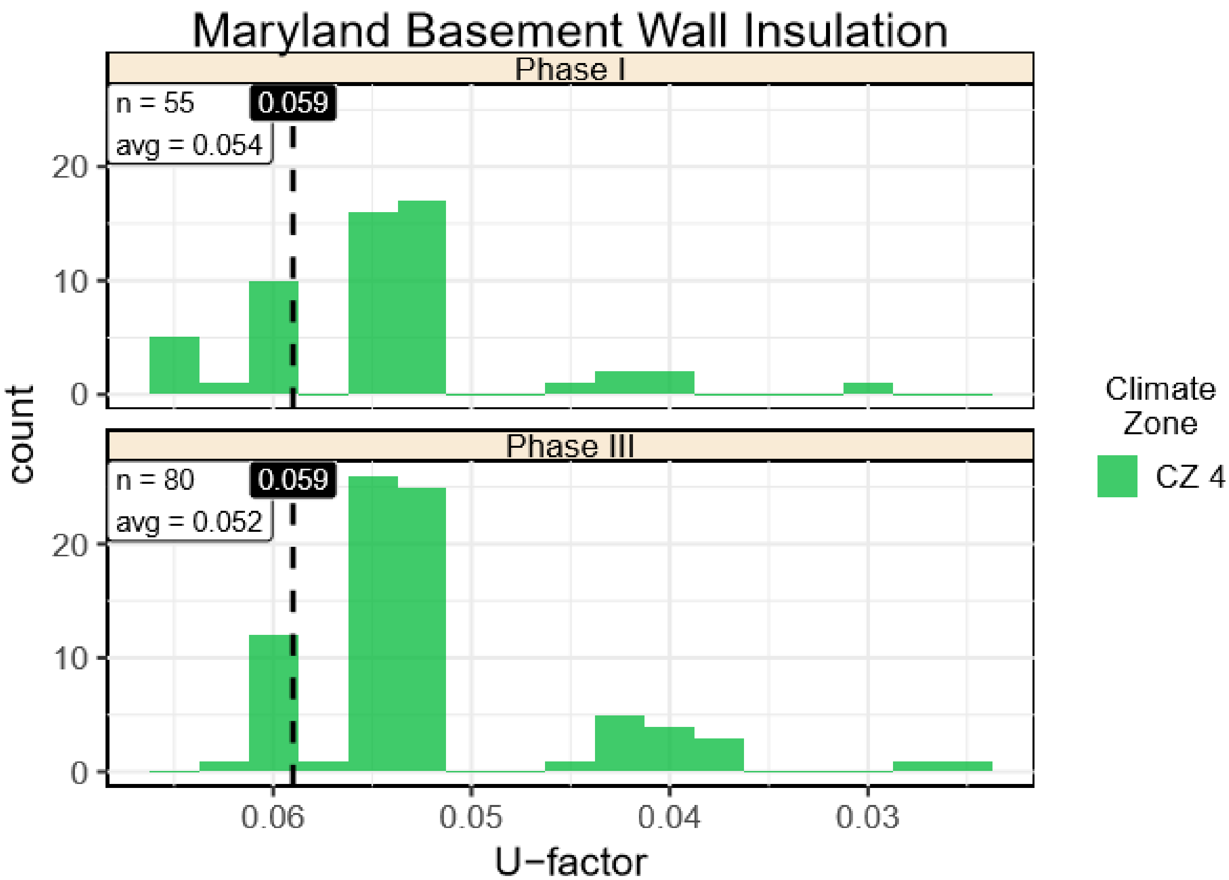

Figure 3.10. Comparison of Phase I and Phase III Basement Wall U-Factors for Maryland

Table 3.13. Maryland Basement Wall U-Factors in Phase I and Phase III

Basement Wall U	MD Phase I	MD Phase III
Requirement	U-0.059	U-0.059
Observations		
Number	55	80
Range	U-0.065 to U-0.029	U-0.063 to U-0.025
Average	U-0.054	U-0.052
Compliance Rate	49 of 55 (89%)	79 of 80 (99%)

- **Interpretations:**
  - The R-value graphs indicate that most basement walls have enough insulation.

– IIQ was relatively high in Phase I and improved to 100% Grade I in Phase III and is likely the reason the U-factor graph indicates nearly all basement walls met the requirement in Phase III.

Floors

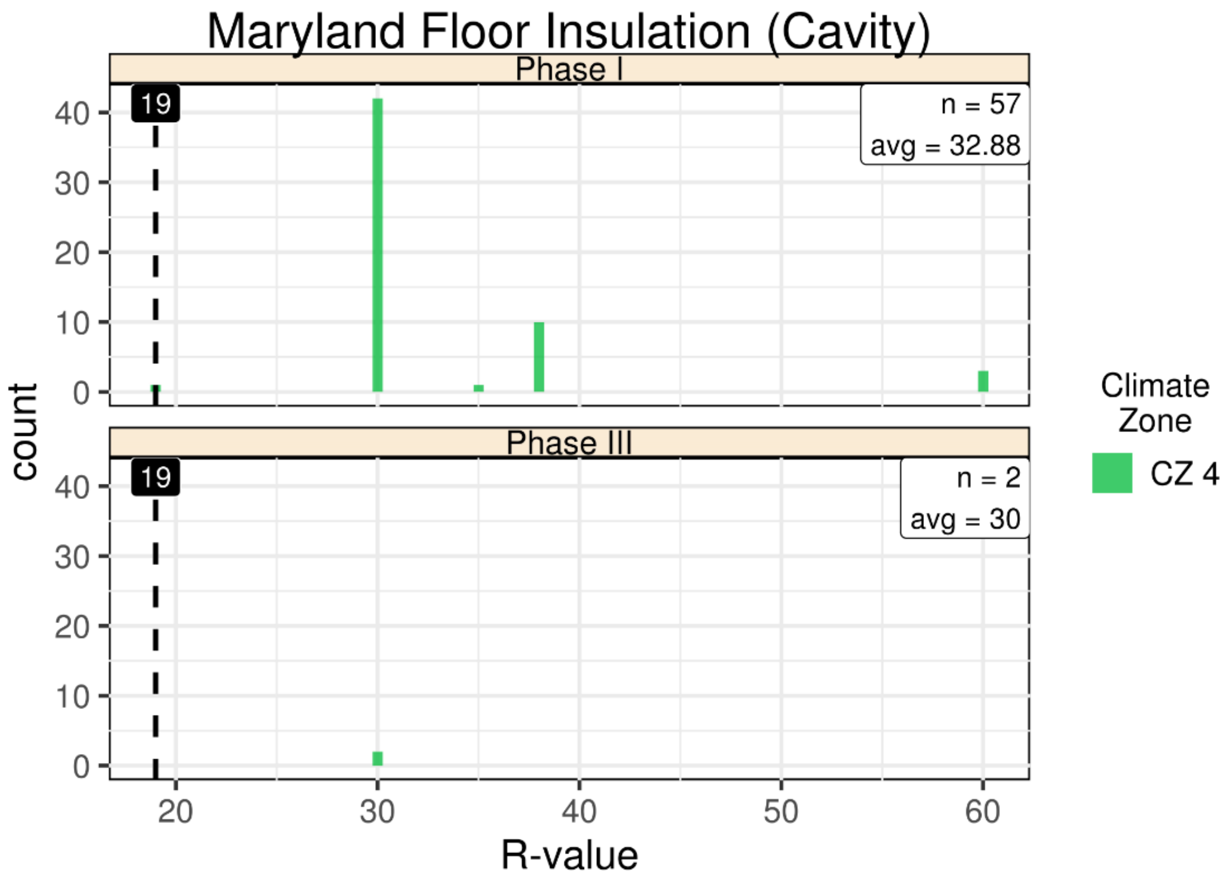

Figure 3.11. Comparison of Phase I and Phase III Floor R-Values for Maryland

Table 3.14 shows the number and percentage of IIQ observations by grade for floor insulation for Phase I and Phase III. Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.12. Given the low number of observations in Phase III, it is difficult to draw any conclusions.

Table 3.14. Floor IIQ Comparison between Phase I and Phase III for Maryland

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Floor Observations	45 / 2	11 / 0	1 / 0	**57 / 2**
Floor Percentages	79% / 100%	19% / 0%	2% / 0%	**100% / 100%**

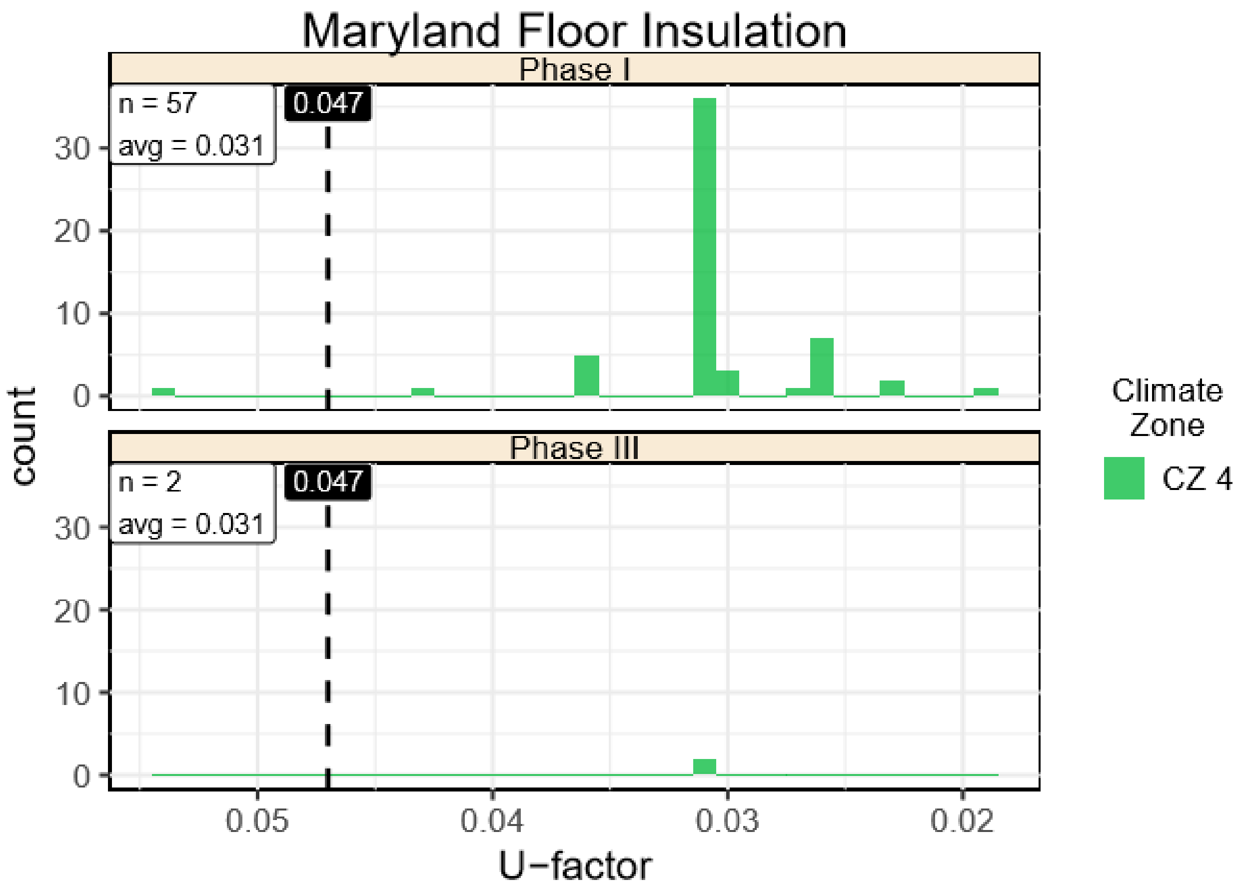

Figure 3.12. Comparison of Phase I and Phase III Floor U-Factors for Maryland

Table 3.15. Maryland Floor U-Factors in Phase I and Phase III

Floor U	MD Phase I	MD Phase III
Requirement	U-0.047	U-0.047
Observations		
Number	57	2
Range	U-0.054 to U-0.019	U-0.031 to U-0.031
Average	U-0.031	U-0.031
Compliance Rate	56 of 57 (98%)	2 of 2 (100%)

- **Interpretations:**
  - Cavity insulation was achieved at a high rate in both Phases—most observations greatly exceeded the prescriptive code requirement (based on labeled R-value). IIQ was also very good. Floor insulation does not appear to be an issue in Maryland.

Slabs

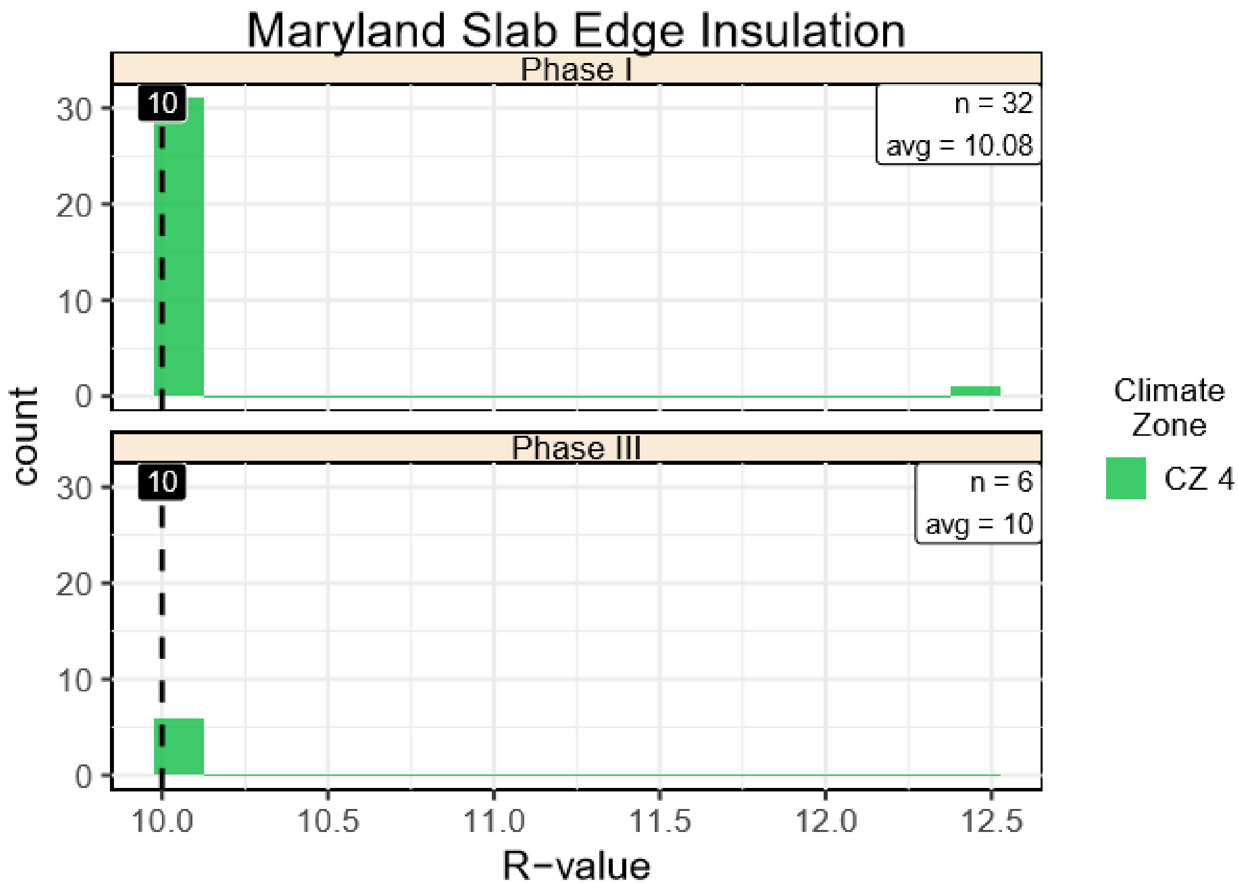

Figure 3.13. Comparison of Phase I and Phase III Slab R-Values for Maryland

Table 3.16. Maryland Slab R-Values in Phase I and Phase III

Slab R	MD Phase I	MD Phase III
Requirement	10	10
Observations		
Number	32	6
Range	R-10 to R-12.5	R-10
Average	R-10	R-10
Compliance Rate	32 of 32 (100%)	6 of 6 (100%)

- **Interpretations:**
  – All slab edge insulation observations in both Phases met the code requirements.

3.1.1.8 Duct Tightness

For ducts, this report presents both unadjusted (raw) duct tightness and adjusted duct tightness. Unadjusted duct tightness is simply the values of duct leakage observed in the field. Adjusted duct tightness looks at the location of the ducts and adjusts the leakage values for any ducts which are entirely in conditioned space by setting the leakage of those ducts to zero (0). The adjustment reflects the fact that duct tightness tests are not required if the ducts are entirely in conditioned space.

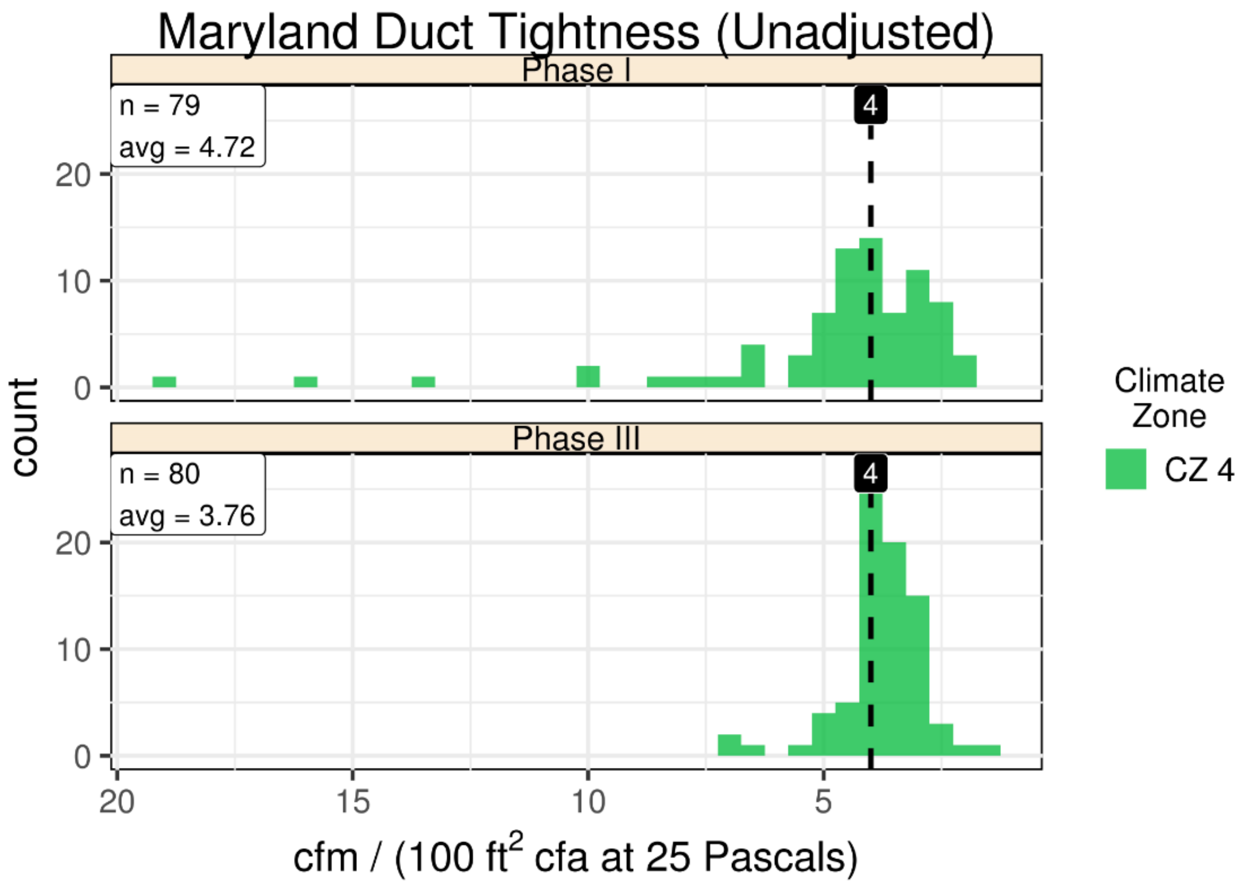

Figure 3.14. Comparison of Phase I and Phase III Duct Tightness Values for Maryland

Table 3.17. Maryland Duct Tightness Values in Phase I and Phase III (unadjusted)

Duct Tightness	MD Phase I	MD Phase III
Requirement	4.0 CFM25/100ft^2 CFA	4.0 CFM25/100ft^2 CFA
Observations		
Number	79	80
Range	19.00 to 1.75	6.9 to 1.3
Average	4.7	3.8
Compliance Rate	40 of 79 (51%)	67 of 80 (84%)

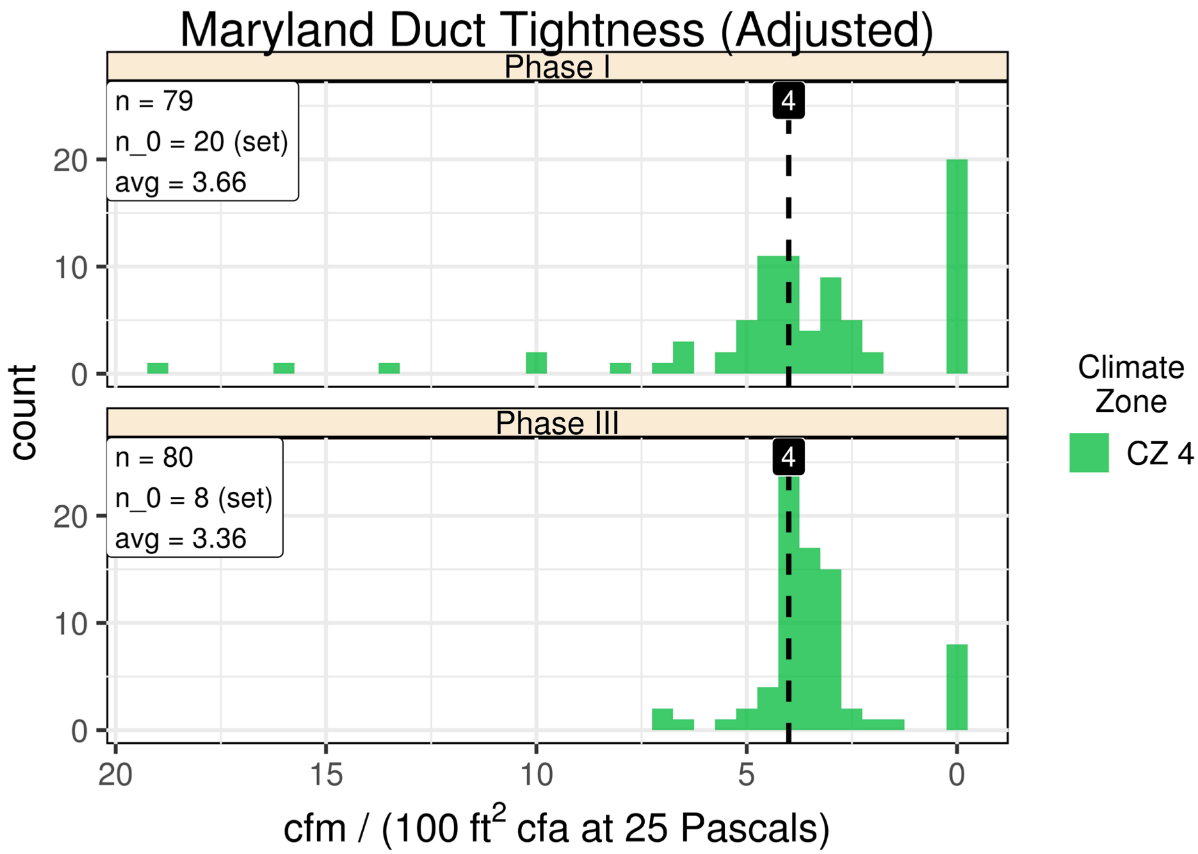

Figure 3.15. Comparison of Phase I and Phase III Adjusted Duct Tightness Values for Maryland

Table 3.18. Maryland Duct Tightness Values in Phase I and Phase III (adjusted)

Duct Tightness Adj	MD Phase I	MD Phase III
Requirement	4.0 CFM25/100ft^2 CFA	4.0 CFM25/100ft^2 CFA
Observations		
Number	79	80
Range	19.00 to 0.0	6.9 to 0.0
Average	3.7	3.4
Compliance Rate	49 of 79 (62%)	70 of 80 (88%)

- **Interpretations:**
  - For unadjusted duct tightness, the distribution of Phase I observations exhibited higher leakage than expected compared to the current code requirement. There was also a large range of results. Duct tightness was a focus of Phase II education and training activities, and results improved in Phase III, with the average being less than the code requirement. It is also notable that the number of outliers in the distribution was greatly reduced.
  - The average unadjusted duct tightness amounts in Phase I were 4.9 in unconditioned space and 4.2 for ducts 100% in conditioned space. In Phase III, averages were 3.7 in unconditioned space and 4.0 for ducts 100% in conditioned space.

– For adjusted duct tightness, the distributions in both Phase I and Phase III have averages below the current code requirement, with Phase III results being slightly better. However, Phase I shows a higher number of ducts entirely in conditioned space.

3.1.2 Additional Data Items

The project team collected data on all code requirements within the state as well as other items to inform the energy simulation and analysis for the project (e.g., home size, installed equipment systems, etc.). While these items were not the focal point of the study, and many are not considered statistically representative, they do provide some insight surrounding the energy code and residential construction within the state.

The following represents a summary of this data and outlines some of the more significant findings, in many cases including the observation or compliance rate associated with the specified item. A larger selection of the additional data items collected as part of the Maryland field study is contained in Appendix C. The full data set is also available on the DOE Building Energy Codes Program website.[9]

The percentages provided in the section below represent percentages of total observations or the percentage of observations that complied.

3.1.2.1 Average Home

Table 3.19. Average Home

Home Statistics	Phase I	Phase III
Number of Observations	206	185
Average Square Footage (ft^2)	3232	3856
Number of Stories	2.35	2.24

3.1.2.2 Compliance

In Phase I, the majority of homes were permitted under the 2015 IECC (64%) or 2012 IECC (30%). In Phase III, all homes were permitted under the 2015 IECC. Approximately half of the homes (49%) participated in an above-code program[10] in Phase I and 10% in Phase III.

[9] Available at https://www.energycodes.gov/residential-energy-code-field-studies.
[10] *All* of the homes which were participating in an above-code program were found to be participating in the ENERGY STAR for Homes program

3.1.2.3 Envelope

Table 3.20. Envelope

Requirement	Phase I	Phase III
Profile		
Walls	Majority wood-framed with mix of 4” (54%), 6” (46%), (n=97)	Majority framed (99%) (n=109)
Foundations	n=205	n=185
Basement	53%	69%
Slab-on-grade	44%	30%
Crawl space	3%	1%
Insulation labeled	99% (n=73)	100% (n=74)
Lighting fixtures sealed	99% (n=145)	100% (n=73)
Utility penetrations sealed	98% (n=65)	100% (n=73)
Attic hatches and doors complied	26% (n=69)	100% (n=79)
Attic access openings sealed	65% (n=74)	100% (n=78)

3.1.2.4 Duct & Piping Systems

Table 3.21. Duct and Piping Systems

Requirement	Phase I	Phase III
Profile		
Supply ducts located within conditioned space (percentage of duct system)	67% (n=159)	50% (n=215)
Return ducts located within conditioned space (percentage of duct system)	76% (n=159)	50% (n=215)
Supply ducts entirely within conditioned space (percentage of homes and number)	28% (44 homes)	20% (43 homes)
Return ducts entirely within conditioned space (percentage of homes and number)	61% (97 homes)	22% (47 homes)
Duct Insulation[11]	R-7.4 (n=521)	R-8.0 (n=674)
Pipe Insulation	R-3 (n=55)	NA
Building cavities not used as supply ducts	96% (n=79)	100% (n=100)
Air handlers sealed	29% (n=156)	100% (n=181)
Filter boxes sealed	43% (n=157)	100% (n=181)

[11] Number of observations for duct insulation include roughly 170 individual observations for both supply and return ducts in attics and in unconditioned space.

Successes

As a percentage of compliant observations, areas identified for improvement in Phase I including sealing of attic hatches and doors, attic access openings, and air handlers and filter boxes improved in Phase III.

3.1.2.5 HVAC Equipment

Table 3.22. HVAC Equipment

Requirement	Phase I	Phase III
Profile		
Heating equipment type	Mostly gas furnaces with some heat pumps (n=137, 137 gas furnace, 21 electric heat pump, and1 electric resistance strip heat)	Mostly gas furnaces with some heat pumps (n=174, 148 gas furnace and 26 electric heat pump)
Heating equipment efficiency	92 AFUE furnace, 7.7 HSPF heat pump (n=152 total)	Not collected
Cooling equipment type	Majority central AC (n=118, 104 central AC, 14 heat pump)	Not collected
Cooling equipment efficiency	13.3 SEER	Not collected
Water heating equipment type	Mostly storage, split between gas and electric (n=103, 55 gas storage, 48 electric storage, and 1 gas tankless)	Mostly gas storage (n=91, 50 gas storage, 25 electric storage, and 16 gas tankless)
Water heating equipment capacity	62 gallons (n=99)	56 gallons (n=66)[12]
Water heating equipment efficiency	EF 0.78 (n=101)	EF 0.80 (n=81)

3.2 Energy Use Intensity

The statewide energy analysis results in Figure 3.16 show the study was successful, with a measurable decrease in statewide EUI between Phase I and Phase III. The change in EUI of 2.98 kBtu/ft^2 is greater than 1.25 kBtu/ft^2 and is therefore considered statistically significant. The observed data set (as gathered in the field) was compared against the same set of homes meeting prescriptive code requirements. Average energy consumption decreased by almost 10% between Phase I and Phase III. Table 3.23 compares the Phase I and Phase III results.

[12] See Table C.13 in Appendix C for additional data on water heater size ranges.

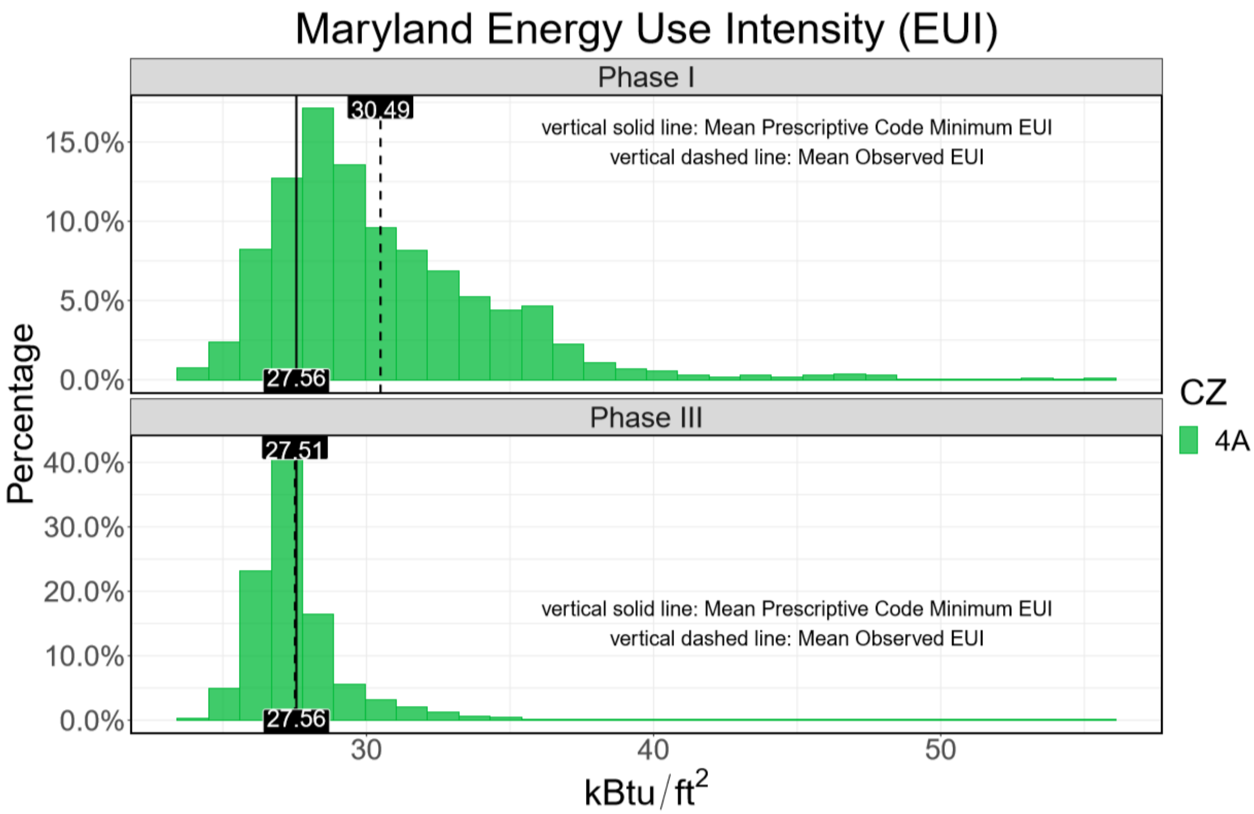

Figure 3.16. Comparison of Phase I and Phase III Statewide EUI for Maryland

Table 3.23. Maryland Statewide EUI in Phase I and Phase III

Prescriptive EUI[13]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
27.56	30.49	10.6%	27.51	-0.2%	-9.8%

3.3 Savings Potential

Several key items in Phase I were previously identified as exhibiting the potential for improvement. Those with the greatest potential[14], shown below followed by the percent that met code, were analyzed further to calculate the associated savings potential, including energy, cost and carbon savings.

[13] Calculated based on the minimum prescriptive requirements of the state energy code.
[14] Defined here as those with less than 85% of observations meeting the prescriptive code requirement

Table 3.24. Comparison of Phase I and Phase III Compliance Rates by Measure in Maryland

Measure	Phase I Compliance Rate	Phase III Compliance Rate	Phase III to Phase I Difference in Compliance Rate
Duct Tightness[15]	62%	88%	+26%
Ceiling Insulation	69%	94%	+25%
Envelope Air Tightness	54%	65%	+11%
Lighting	61%	96%	+35%
Exterior Wall Insulation	25%	26%	+1%

For analytical details refer to Section 2.3.3 (Savings Analysis) or the methodology report (DOE 2018).

The results of the energy savings potential analysis after Phase I and Phase III are shown in Table 3.25. The results indicate that the Phase II education and training activities were successful in reducing the overall savings potential for all measures as a whole using all three metrics (energy, energy cost, and emissions reduction). In this case, improvement is achieved through a reduction in measure-level savings potential between Phase I and Phase III.

Table 3.25. Comparison of Phase I and Phase III Estimated Annual Statewide Savings Potential

	Potential Total Energy Savings (MMBtu)		Potential Total Energy Cost Savings ($)		Potential Total State Emissions Reduction (MT CO2e)	
Measure	**Phase I**	**Phase III**	**Phase I**	**Phase III**	**Phase I**	**Phase III**
Envelope Air Tightness	53,868	13,923	754,946	194,899	3,569	887
Ceiling Insulation	2,569	597	44,366	10,307	216	49
Exterior Wall Insulation	25,230	4,594	401,480	73,498	1,934	345
Lighting	3,566	155	195,378	8,115	1,032	44
Duct Tightness	8,108	1,324	146,619	24,595	718	119
TOTAL	**93,341 MMBtu**	**20,593 MMBtu**	**$1,542,789**	**$311,414**	**7,469MT CO2e**	**1,443 MT C02e**

On an individual measure basis, the Phase II education and training activities were successful in reducing the savings potential for all measures and especially for envelope air tightness, wall insulation, and lighting. The measure-level energy cost savings for envelope air tightness showed a reduction of 74%, wall insulation showed a reduction of 82%, and lighting 96%.

Overall energy cost measure-level savings showed an 80% reduction between Phase I and Phase III. Potential annual savings accumulate over time. Table 3.26 compares energy cost savings between Phase I and Phase III accumulated over 5, 10, and 30 years of construction. For additional details on electricity savings and natural gas savings per home associated with each measure; savings by individual foundation components; and how the total savings and emissions reductions accumulate over 5, 10, and 30 years of construction, see Appendix D.

[15] This compliance rate is for adjusted duct tightness observations.

Table 3.26. Comparison of Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Phase III vs. Phase I

Measure	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
Duct Tightness	11,324,190	2,923,489	41,522,030	10,719,461	351,049,890	90,628,174
Lighting	6,022,185	1,102,477	22,081,345	4,042,416	186,687,735	34,176,789
Envelope Air Tightness	2,930,670	368,918	10,745,790	1,352,698	90,850,770	11,436,450
Exterior Wall Insulation	2,199,285	121,721	8,064,045	446,310	68,177,835	3,773,350
Ceiling Insulation	665,490	154,606	2,440,130	566,887	20,630,190	4,792,774
TOTAL	**$23,141,835**	**$4,671,211**	**84,853,395**	**$17,127,773**	**$717,396,420**	**$144,807,538**

4.0 Conclusions

Success for the Maryland study was characterized by the following between Phase I and Phase III: 1) a measurable change in statewide energy use (a change in EUI of at least 1.25 $kBtu/ft^2$) and 2) a reduction in measure-level savings potential. Based on those metrics, the Maryland field study was successful and showed that targeted education and training can influence a measurable change in statewide energy consumption and a reduction in measure-level savings potential. A reduction in savings potential equates to improvement.

At the time of the study, the state had the 2015 International Energy Conservation Code (IECC), which was adopted shortly before the start of Phase I, making it one of the first to implement that model code and creating a unique opportunity for the study. From a statewide perspective, the average home in Maryland is now saving even more energy than a home exactly meeting the state energy code, moving from 10.6 percent more energy than a code home in Phase I to 0.2 percent less energy in Phase III as shown in Table 4.1. This results in over $1,200,000 in annual achieved savings, an improvement of nearly 20% following the Phase II targeted education and training activities as shown in Table 4.2. See Table 3.25 for potential total energy cost savings in each phase.

Table 4.1. Average Modeled Energy Use Intensity in Maryland (kBtu/ft2-yr)

Prescriptive EUI[1]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
27.56	30.49	+10.6%	27.51	-0.2%	-9.8%

The contributing factor to the reduction in measure-level savings potential was improvements in all key items that were noted to be issues in Phase I.

Table 4.2. Estimated Annual Statewide Cost Savings Potential

Measure	% Change Phase III vs. I
Envelope Air Tightness	74.2%
Ceiling Insulation	23.2%
Exterior Wall Insulation	81.2%
Lighting	76.8%
Duct Tightness	83.2%
TOTAL	**79.8%**

This project provides the state with significant and quantified data that can be used to help direct future energy efficiency activities. DOE encourages states to conduct these types of studies every 3-5 years to validate state code implementation, quantify related benefits achieved, and identify ongoing opportunities to hone education and training programs.

[1] Calculated based on the minimum prescriptive requirements of the state energy code.

5.0 References

DOE. 2012. *National Energy and Cost Savings for New Single- and Multifamily Homes: A Comparison of the 2006, 2009, and 2012 Editions of the IECC*. https://www.energycodes.gov/sites/default/files/2020-06/NationalResidentialCostEffectiveness_2009_2012.pdf

DOE Building Energy Codes Program's residential field study website is available at https://www.energycodes.gov/residential-energy-code-field-studies.

DOE 2018. "Residential Building Energy Code Field Study: Data Collection and Analysis." Available at https://www.energy.gov/eere/buildings/downloads/energy-code-field-studies

EnergyPlus. https://energyplus.net/.

The Maryland residential field study website is available at http://newportpartnersllc.com/projects/residential_energy_efficiency.html (accessed March 2, 2020).

Newport Partners. 2018. Press Release: "Measuring the Value of Education and Training on the Maryland Energy Code Project Results." Newport Partners LLC, Davidsonville, MD. http://newportpartnersllc.com/PDFs/MEA_Project_Results.pdf (accessed March 2, 2020).

Residential Energy Services Network. 2013. "Mortgage Industry National Home Energy Rating System Standards." Residential Energy Services Network, Oceanside, CA. www.resnet.us.

Appendix A

Stakeholder Participation

Appendix A

Stakeholder Participation

A.1 Stakeholder Participation

Table A.1. Stakeholder Participation in Project Kickoff Meeting

Stakeholder	Description
Maryland Building Industry Association (MBIA)	Trade organization representing builders, remodelers, developers and affiliated professionals.
Maryland AIA	A state component of the AIA with over 1,500 members, representing architects and allied professionals.
Maryland Building Officials Association	Membership organization for code officials aimed at improving code enforcement practices across Maryland.
Maryland Department of Housing & Community Development	The Building Codes Administration works with local governments, design professionals and code inspectors to uphold construction standards.
Maryland Energy Administration	MEA's mission is to promote affordable, reliable and clean energy, with programs to lower energy bills, fuel job creation, and address environmental impacts.
Southern Maryland Electric Cooperative (SMECO)	Customer-owned electric cooperative providing service to more than 160,000 accounts in various Maryland counties.
Carroll County Bureau of Permits & Inspections	Government agency responsible for local code administration and enforcement in Carroll County.
Cecil County Department of Inspections & Licensing	Provides permitting, inspection and code enforcement services to Cecil County.
Harford County Department of Inspections, Licenses & Permits	Government agency responsible for local code administration and enforcement in Harford County.
Howard County Department of Inspections, Licensing & Permitting	Clearinghouse for permits, reviewing construction documents, and inspecting buildings for code compliance.
Montgomery County Division of Building Design & Construction	Agency responsible for planning, designing and constructing Montgomery County's public buildings.
Prince George's Department of Permits, Inspections & Enforcement	Government agency responsible for permitting, business licensing inspections and property code enforcement.

Appendix B

State Sampling Plan

Appendix B

State Sampling Plan

B.1 State Sampling Plan

Table B.1. Phase I State Sampling Plan

Location	Sample	Actual*
Montgomery County Unincorporated Area, Montgomery	5	**6**
Howard County, Howard	4	4
Anne Arundel County Unincorporated Area, Anne Arundel	12	**14**
Prince Georges County Unincorporated Area, Prince George	6	6
Charles County Unincorporated Area, Charles	2	2
Baltimore County, Baltimore	9	**7**
Frederick County Unincorporated Area, Frederick	3	**2**
Harford County Unincorporated Area, Harford	4	**3**
St. Marys County Unincorporated Area, St. Mary's	3	3
Carroll County, Carroll	1	1
Calvert County, Calvert	3	3
Cecil County Unincorporated Area, Cecil	2	**1**
Frederick, Frederick	1	1
Baltimore, Baltimore (city)	2	2
Easton town, Talbot	1	1
Worcester County Unincorporated Area, Worcester	1	1
Wicomico County Unincorporated Area, Wicomico	1	**2**
Havre de Grace, Harford	1	1
Aberdeen, Harford	1	**2**
Dorchester County Unincorporated Area, Dorchester	1	1
Total	**63**	**63**

*Counts marked in bold indicate a substitution was made in Phase I.

Table B.2. Phase III State Sampling Plan

Location	Sample	Actual
Montgomery County Unincorporated Area, Montgomery	13	13
Howard County, Howard	13	13
Anne Arundel County Unincorporated Area, Anne Arundel	10	10
Prince Georges County Unincorporated Area, Prince George	6	6
Charles County Unincorporated Area, Charles	3	3
Frederick County Unincorporated Area, Frederick	2	2

Location	Sample	Actual
Harford County Unincorporated Area, Harford	4	4
St. Marys County Unincorporated Area, St. Mary's	1	1
Carroll County, Carroll	3	3
Calvert County, Calvert	2	2
Frederick, Frederick	1	1
Baltimore, Baltimore (city)	4	4
Washington County Unincorporated Area, Washington	1	1
Total	**63**	**63**

B.2 Substitutions

In the Phase I Maryland study, several substitutions were made, as noted in the table above. The reasons for the substitutions included:

- **Housing Stock**–some jurisdictions simply did not have the housing stock to support the sample size across all key items;
- **Accessibility**–some builders chose not to grant site access; and
- **Construction Process**–although permits were pulled months prior to the site visit, construction had not begun or was not at a phase where key items could be observed.

There were no substitutions in Phase III.

Appendix C

Additional Data

Appendix C

Additional Data

C.1 Additional Data Collected by Field Teams

The project team 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 state, while others were collected to inform the energy simulation and analysis for the project (e.g., installed equipment, whether the home participated in an above-code program, etc.). While these items were not the focal point of the study, and many are not considered statistically representative, they do provide some additional insight surrounding the energy code and residential construction within the state.

The following is a sampling of the additional data items collected as part of the Maryland field study. 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.[1]

C.1.1 General

The following represents the general characteristics of the homes observed in the study:

C.1.1.1 Average Home

Table C.1. Home Size

Home Statistics	Phase I	Phase III
Number of Observations	206	185
Average Square Footage (ft^2)	3232	3856
Number of Stories	2.35	2.24
Number of Bedrooms	3.78	3.88

Table C.2. Conditioned Floor Area (ft^2)

Conditioned Floor Area (ft^2)	< 1000	1000 to 1999	2000 to 2999	3000 to 3999	4000+
Percentage (Phase I)	0%	42%	32%	19%	7%
Percentage (Phase III)	1%	35%	24%	20%	20%

Table C.3. Number of Stories

No. of Stories	1	2	3	4+
Percentage (Phase I)	2%	48%	47%	4%
Percentage (Phase III)	4%	70%	25%	1%

[1] Available at https://www.energycodes.gov/residential-energy-code-field-studies

C.1.1.2 Wall Profile

Table C.4. Wall Characteristics

Wall Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Framing Type			164	109
Frame Walls	100%	99%		
Mass Walls	0%	1%		
Framing Material			97	94
Wood	99%	100%		
Steel	1%	0%		
Framing Depth			97	93
4 inch	54%	40		
6 inch	46%	60		
Type of Wall Insulation			56	69
Cavity Only	54%	48%		
Cavity + Continuous	46%	52%		
Continuous Only	0%	0%		

C.1.1.3 Foundation Profile

Table C.5. Foundation Characteristics

Foundation Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Foundation Type			205	185
Basement	53%	69%		
Slab on Grade	44%	30%		
Crawlspace	3%	1%		
Basement Type			104	127
Conditioned	98%	100%		
Unconditioned	2%	0%		

C.1.1.4 Builder Profile

Table C.6. Builder Characteristics

Builder Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations*
Number of Homes Built Annually	125	101	206	185
Distribution of Number of Homes Built Annually			206	185
Less than 10	12%	20%		
10 to 50	19%	19%		
50 to 99	17	17%		
100+	52%	44%		

*Only 5 observations in Phase III, with 4 observations of same builder

C.1.2 Compliance

The following summarizes information related to compliance, including the energy code associated with individual homes, whether the home was participating in an above code program, and which particular programs were reported. The percentages provided in the sections below represent percentages of total observations or the percentage of observations that complied.

C.1.2.1 Energy Code Used

Table C.7. Energy Code and Above Code Programs

Code or Above Code Program Used	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Energy Code Used			206	185
2009 IECC	6%			
2012 IECC	30%			
2015 IECC	64%	100%		
Was home participating in an above code program?			156	106
Yes	49%	10%		
No	51%	90%		
Which above code program?			77	11
Energy Star for Homes	100%	100%		

C.1.3 Envelope

The following list of questions focuses on average characteristics of the thermal envelope:

Table C.8. Thermal Envelope Characteristics

Thermal Envelope Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Was insulation labeled?			73	74
Yes	99%	100%		
No	1%	0%		
Did the attic hatch/door exhibit the correct insulation value?			69	79
Yes	26%	100%		
No	74%	0%		
Air Sealing in accordance with checklist[1]				
Thermal Envelope sealed?	100%	100%	64	73
Fenestration Sealed?	100%	100%	64	73
Openings around doors and windows sealed?	100%	100%	64	73
Utility penetrations sealed?	98%	100%	65	73
Dropped ceilings sealed?[2]	88%	100%	60	73
Knee walls sealed?	74%	NA	35	0
Garage walls sealed?	83%	100	66	69
Tubs and showers sealed?	81%	100%	64	61
Attic access openings sealed?	65%	100%	74	78
Rim joists sealed?	100%	100%	75	132
Other sources of infiltration sealed?	100%	100%	64	61
IC-rated light fixtures sealed?	99%	100%	145	73

C.1.4 Duct & Piping Systems

The following represents an average profile of observed air ducting and water piping systems, followed by a list of additional questions related to such systems:

Table C.9. Duct & Piping System Characteristics

Duct & Piping System Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Duct location in conditioned space (average percentage)				
Supply	67%	58%	159	162
Return	76%	59%	159	162

[1] 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.
[2] 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.

Duct & Piping System Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Ducts entirely in conditioned space (number and percentage)				
Supply	44 duct systems (27%)	52 duct systems (24%)		
Return	97 duct systems (61%)	56 duct systems (26%)		
Ducts in unconditioned space insulation (R-value)				
Supply	7.5	8.0	138	171
Return	7.4	8.0	132	167
Ducts in attic insulation (R-value)				
Supply	7.4	8.0	127	170
Return	7.4	8.0	124	166
Pipe insulation (R-value)			105	106
Average	R-3	NA		
Range	All R-3	NA		
Building cavities used as supply ducts	4%	0%	79	100
Air ducts sealed	91%	100%	86	100
Air handlers sealed	71%	100%	156	181
Filter boxes sealed	57%	100%	157	181

C.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:

C.1.5.1 Heating

Table C.10. Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			159	174
Gas	86%	85%		
Electricity	14%	15%		
System Type			159	174
Furnace	86	85%		
Heat Pump	13%	15%		
Electric Resistance	1%	0%		
Average System Capacity			150	NA*
Furnace	64,000 Btu/hr	NA*		
Heat Pump	32,500 Btu/hr	NA*		
Average System Efficiency			152	NA*

Furnace	93 AFUE	NA*
Heat Pump	8 HSPF	NA*

*Heating system capacity and system efficiency not collected in Phase III.

C.1.5.2 Cooling

Table C.11. Cooling Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			118	NA*
Central AC	88%	NA*		
Heat Pump	12%	NA*		
Average System Capacity			89	NA*
Central AC	32,000 Btu/hr	NA*		
Heat Pump	25,800 Btu/hr	NA*		
Average System Efficiency			70	NA*
Central AC	13.2 SEER	NA*		
Heat Pump	13.0 SEER	NA*		

*Cooling system type, system capacity and system efficiency not collected in Phase III.

C.1.5.3 Water Heating

Table C.12. Water Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			104	92
Gas	46%	72%		
Electricity	54%	28%		
System Type			103	91
Storage	99%	82%		
Tankless	1%	18%		
Average System Capacity	62 gal	56 gal	99	66
Average System Efficiency			101	81
Electric Storage (non-heat pump)	EF 0.90	EF 0.93	101	25
Gas Storage	EF 0.65	EF 0.67	101	41
Gas Tankless	EF 0.94	EF 0.97	101	15

Table C.13. Water Heating System Storage Capacity Distribution

Capacity	< 50 gal	50-59 gal	60-69 gal	70-79 gal	80-89 gal	90+ gal
Phase I Percentage	0%	49%	13%	17%	20%	0%
Phase III Percentage	5%	73%	1%	18%	0%	3%

C.1.5.4 Ventilation

Table C.14. Ventilation Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			79	18
Exhaust Only	89%	100%		
AHU-Integrated	9%			
Standalone ERV/HRV	1%			
Standalone ERV	1%			
Exhaust Fan Type			70	11
Dedicated Exhaust	90%	10%		
Bathroom Fan	10%	100%		

C.1.5.5 Other

Table C.15. Other Mechanical System Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Mechanical Manuals Provided	92%	100%	36	78

Appendix D

Energy Savings

Appendix D

Energy Savings

D.1 Measure-Level Savings

This appendix contains detailed measure-level annual savings results for both Phase I (Table D.1 and Phase III (Table D.2) for Maryland. Also included are multi-year (5-year, 10-year, and 30-year) aggregations of the annual results in Table D.3, Table D.4, and Table D.5. 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 Section 2.3.3 (Savings Analysis) or the methodology report (DOE 2018).

Table D.1. Phase I Statewide Annual Measure-Level Savings for Maryland

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Tightness	133	47	5,110	10,541	53,868	754,946	3,569
Exterior Wall Insulation	111	20	2,393	10,541	25,230	401,480	1,934
Lighting*	157	-2	338	10,541	3,566	195,378	1,032
Duct Tightness	54	6	769	10,541	8,108	146,619	718
Ceiling Insulation	15	2	244	10,541	2,569	44,366	216
TOTAL	**470**	**72**	**8,855**	**10,541**	**93,341**	**1,542,789**	**7,469**

* Negative values mean that savings or reductions decrease if the measure is brought up to code. For example, for lighting, increasing the amount of high-efficacy lighting reduces electrical usage, but increases natural gas usage for heating, as the heat from less efficient bulbs must be replaced.

Table D.2. Phase III Statewide Annual Measure-Level Savings for Maryland

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Tightness	34	12	1,321	10,541	13,923	194,899	887
Exterior Wall Insulation	21	4	436	10,541	4,594	73,498	345
Lighting*	6	0	15	10,541	155	8,115	44
Duct Tightness	9	1	126	10,541	1,324	24,595	119
Ceiling Insulation	3	0	57	10,541	597	10,307	49
TOTAL	**74**	**17**	**1,954**	**10,541**	**20,593**	**311,414**	**1,443**

* Negative values mean that savings or reductions decrease if the measure is brought up to code. For example, for lighting, increasing the amount of high-efficacy lighting reduces electrical usage, but increases natural gas usage for heating, as the heat from less efficient bulbs must be replaced.

Table D.3. Phase I Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings for Maryland

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	808,020	2,962,740	25,048,620	11,324,190	41,522,030	351,049,890	53,535	196,295	1,659,585
Lighting	378,450	1,387,650	11,731,950	6,022,185	22,081,345	186,687,735	29,010	106,370	899,310
Envelope Air Tightness	53,490	196,130	1,658,190	2,930,670	10,745,790	90,850,770	15,480	56,760	479,880
Exterior Wall Insulation	121,620	445,940	3,770,220	2,199,285	8,064,045	68,177,835	10,770	39,490	333,870
Ceiling Insulation	38,535	141,295	1,194,585	665,490	2,440,130	20,630,190	3,240	11,880	100,440
TOTAL	**1,400,115**	**5,133,755**	**43,403,565**	**23,141,835**	**84,853,395**	**717,396,420**	**112,035**	**410,795**	**3,473,085**

Table D.4. Phase III Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings for Maryland

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	208,845	765,766	6,474,205	$2,923,489	$10,719,461	$90,628,174	13,301	48,769	412,321
Lighting	68,907	252,659	2,136,115	$1,102,477	$4,042,416	$34,176,789	5,174	18,971	160,391
Envelope Air Tightness	19,861	72,824	615,694	$368,918	$1,352,698	$11,436,450	1,783	6,536	55,261
Exterior Wall Insulation	2,325	8,525	72,077	$121,721	$446,310	$3,773,350	656	2,405	20,336
Ceiling Insulation	8,961	32,856	277,781	$154,606	$566,887	$4,792,774	737	2,702	22,842
TOTAL	**308,899**	**1,132,630**	**9,575,873**	**$4,671,211**	**$17,127,773**	**$144,807,538**	**21,650**	**79,384**	**671,152**

Table D.5. Difference between Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Phase III vs. Phase I

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	599,175	2,196,974	18,574,415	$8,400,701	$30,802,569	$260,421,716	40,234	147,526	1,247,264
Lighting	309,543	1,134,991	9,595,835	$4,919,708	$18,038,929	$152,510,946	23,836	87,399	738,919
Envelope Air Tightness	33,629	123,306	1,042,496	$2,561,752	$9,393,092	$79,414,320	13,697	50,224	424,619
Exterior Wall Insulation	119,295	437,415	3,698,143	$2,077,564	$7,617,735	$64,404,485	10,114	37,085	313,534
Ceiling Insulation	29,574	108,439	916,804	$510,884	$1,873,243	$15,837,416	2,503	9,178	77,598
TOTAL	29,574	108,439	916,804	$510,884	$1,873,243	$15,837,416	2,503	9,178	77,598

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