PNNL-25970

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Maryland Residential Energy Code Field Study: Baseline Report

September 2016

R Bartlett
M Halverson
V Mendon
J Hathaway
Y Xie
M Zhao

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.
(8/2010)

PNNL-25970

Maryland Residential Energy Code Field Study: Baseline Report

R Bartlett
M Halverson
V Mendon
J Hathaway
Y Xie
M Zhao

September 2016

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

A research project in the state of Maryland investigated energy code-related aspects of residential single-family new construction. The study was initiated in January 2015 and continued through July 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 data has led to a better understanding of the energy features present in homes, and indicates over $1.5 million in potential savings to Maryland homeowners that could result from increased code compliance. Public and private entities within the state can use this information to justify and catalyze future investments in energy code training and related energy efficiency programs.

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. The project team implemented a customized sampling plan representative of new construction within the state, which was originally developed by Pacific Northwest National Laboratory (PNNL), and then vetted through public meetings with key stakeholders in the state.

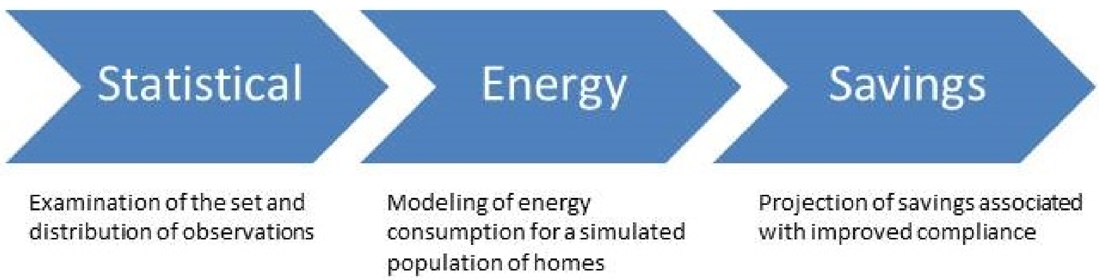

Figure ES.1. Stages of Analysis Applied in the Study

Following data collection, 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 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 the potential energy savings, consumer cost savings, and avoided carbon emissions associated with increased code compliance. Together, these findings provide valuable insight on challenges facing energy code implementation and enforcement, and are intended to inform future energy code education, training and outreach activities.

Results

The key items with the greatest potential for savings in Maryland are presented below (Table ES.1). The estimates presented in the table represent the savings associated with each measure, and are extrapolated based on projected new construction. These items should be considered a focal point for compliance-improvement programs within the state, including energy code educational, training and outreach initiatives.

Table ES.1. Estimated Annual Statewide Savings Potential in Maryland

Measure	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Leakage	53,868	754,946	3,569
Wall Insulation	25,230	401,479	1,934
Lighting	3,566	195,378	1,032
Duct Leakage	8,108	146,619	718
Ceiling Insulation	2,569	44,366	216
TOTAL	**93,341**	**1,542,789**	**7,469**

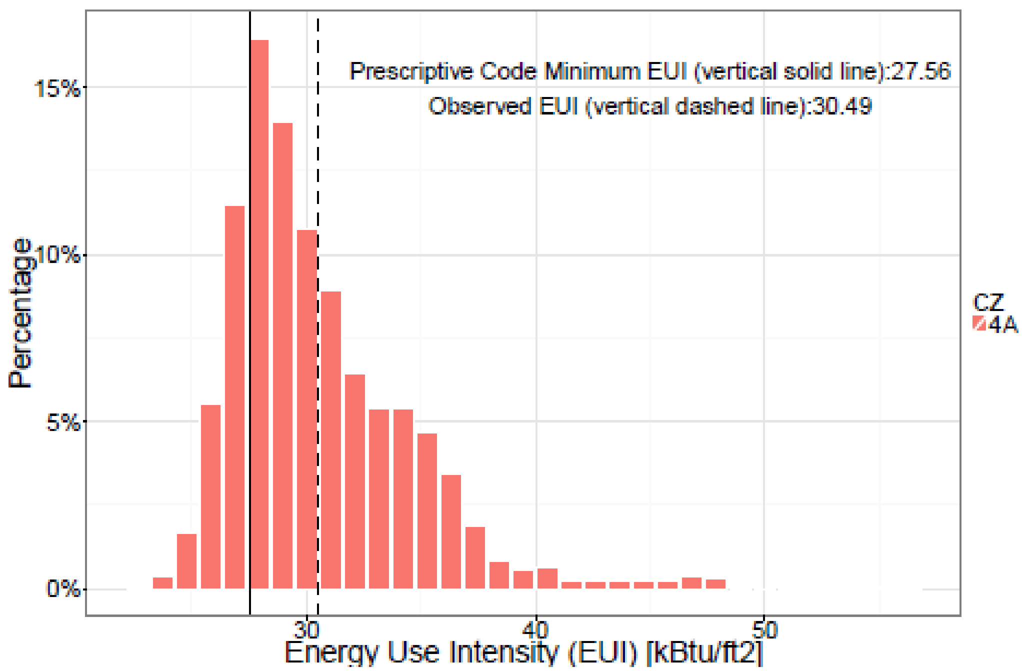

Figure ES.2. Modeled Distribution of Regulated EUI (kBtu/ft^2/year) in Maryland

In terms of overall energy consumption, homes within the state appear to use *more* energy than would be expected relative to homes built to the current minimum state code requirements (Figure ES.2). Analysis of the collected field data indicates average regulated energy use intensity (EUI) of 30.49 kBtu/ft^2-yr statewide compared to 27.56 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements. This suggests that on average the typical home in the state is about 11% worse than code. Tempering this finding is the fact that Maryland has one of the most stringent residential energy codes in the country.

Acknowledgments

The following members comprised the Maryland project team:

- 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
AIA	American Institute of Architects
Btu	British thermal unit
cfm	cubic feet per minute
CZ	climate zone
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EUI	energy use intensity
FOA	funding opportunity announcement
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
NA	not applicable
PNNL	Pacific Northwest National Laboratory
RFI	request for information
SHGC	solar heat gain coefficient
TSD	technical support document

Contents

Figures

Tables

1.0 Introduction

A research project in the state of Maryland investigated the energy code-related aspects of unoccupied, newly constructed, single family homes across the state. The study followed a DOE-prescribed methodology, which allowed the project team to build an empirical data set based on observations made directly in the field. The data was then analyzed to identify compliance trends, their impact on statewide energy consumption, and calculate savings that could be achieved through increased code compliance. Study findings can help to justify additional support for energy code education, training & outreach activities, as well as catalyze future investments in compliance improvement programs.

The Maryland field study was initiated in January 2015 and continued through July 2015. During this period, research teams visited 207 homes across the state during various stages of construction. At the time of the study, the state had recently adopted the 2015 IECC without amendment, making it one of the first to implement the current model code, and creating a unique opportunity for study. The study methodology, data analysis and resulting findings are presented throughout this report. Additional background, information on the project team and others involved with the project are discussed in the following sections.

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), "Strategies to Increase Residential Energy Code Compliance Rates and Measure Results".[1] The goal of the FOA is to determine whether an investment in education, training, and outreach programs can produce a significant, measurable change in single-family residential building code energy use, and therefore energy savings, within 2-3 years. Participating states are:

- Conducting a baseline field study to determine installed energy values of code-required items, identify issues, and calculate savings opportunities;
- Implementing education, training, and outreach activities designed to increase code compliance; and
- Conducting a second field study to measure the post-training values using the same methodology as the baseline study.

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 consumers reap the benefits of improved codes—something which will happen only through high levels of compliance. More information on the FOA and overall DOE interest in compliance is available on the DOE Building Energy Codes Program website.[4]

---

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

[2] *National Energy and Cost Savings for New Single- and Multifamily Homes: A Comparison of the 2006, 2009, and 2012 Editions of the IECC*, available at http://www.energycodes.gov/development

[3] Available at http://www.energycodes.gov/adoption/states

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

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 advocates
- Utilities
- Other important entities identified by the project team

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

Members of these and other groups are critical to the success of the project, as they hold important information (e.g., building officials have the lists of homes under construction and are therefore key to the sampling process), control access to homes needed for site visits, are targets for training, or, as is often the case with government agencies, have oversight responsibilities for code adoption and implementation. Utilities were also identified as a crucial stakeholder, and often have direction from state regulatory bodies (e.g., the public utility commission) to achieve energy savings. 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 is aimed specifically at providing a strong, empirically-based case for such utility investment.

2.0 Methodology

2.1 DOE Protocol

The Maryland field study was based on a methodology developed by DOE to identify energy and cost savings opportunities associated with increased compliance with their residential building energy codes. This methodology involves gathering field data on installed measures, as observed in actual homes. In analyzing this data, compliance trends and issues can be identified, which help to inform energy code training and other compliance improvement programs.

Highlights of the methodology:

- Focuses on **individual code requirements** within **new, unoccupied single-family homes**
- Based on a **single site visit** to reduce burden and minimize bias
- Prioritizes **key items** with the greatest direct impact on energy consumption
- Designed to produce **statistically significant results**
- **Data confidentiality** built into the experiment—no personal data is 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. Window SHGC
3. Window U-factor
4. Exterior wall insulation (assembly U-factor)
5. Ceiling insulation (R-value)
6. Lighting (% high-efficacy)
7. Foundation insulation (R-value)[2]
8. Duct tightness (expressed in 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.

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 full DOE

[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 were combined into a single category of foundation insulation

protocol is published separately from this report (DOE 2016a). Further details on the PNNL analysis are also available in a technical support document (TSD) (DOE 2016b).[3]

2.2 State Study

The prescribed methodology was customized for the state of Maryland 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 a statewide sampling plan 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 plan specified the number of key item observations required in each selected jurisdiction (totaling 63 of each key item across the entire state).

Maryland comprises two climate zones (CZ4 and CZ5). However, the only county in CZ5 is Garrett County in the far western tip of the state, which did not show up in the sampling plan (i.e., due to its smaller population and the randomized nature of the sample). Therefore, all data collected in the state is from a single climate zone (CZ4) and there is no differentiation of results by climate zone.

An initial sample plan was first developed by PNNL, and then vetted by stakeholders within the state. Special considerations were discussed by stakeholders at a project kickoff meeting, such as state-specific construction practices or systematic differences across county or climate zone boundaries. These considerations were taken into account and incorporated into the final statewide sample plan shown in Appendix B.

2.2.2 Data Collection

Following confirmation of the statewide sample plan, the project team began contacting local building departments to identify homes currently in the permitting process. Code officials responded by providing a list of homes at various stages of construction within their jurisdiction. These lists were then sorted using a random number generator and utilized by field personnel to select specific homes to visit and call the builder to gain site access. As prescribed by the methodology, each home was visited only once to avoid any bias associated with multiple site visits—only items that could be observed during this site visit were collected as data. If permission was denied for a particular home on the list, field personnel moved onto the next home on the list.

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

[3] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study
[4] Available at http://censtats.census.gov/ (select the "Building Permits" data)
[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).

final Maryland 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.

Field teams gathered substantial information beyond the key items much of which was used during various phases of the analysis, or to supplement the overall study findings. For example, insulation installation quality impacts the energy-efficiency of insulation, itself, and is therefore used to modify that key item within the later energy modeling and savings calculation. Observed equipment (e.g., fuel type and efficiency rating) and basic home characteristics (e.g., foundation type) help validate the prototype models applied during energy simulation. Other questions, such as whether the home participated in an above-code program, can also assist in understanding whether there may be other influencing factors at play beyond the code requirements.

2.2.2.2 Data Management and Availability

Once the data collection effort was complete, the project team conducted a thorough quality assurance review. This review included an independent check of raw data compared to the information provided to PNNL for analysis, and helped to ensure the 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 is available in spreadsheet format on the DOE Building Energy Codes Program website.[7]

2.3 Data Analysis

All data analysis in the study was performed by PNNL, and was applied through three basic stages:

1. **Statistical:** Examination of the set and distribution of observations for individual measures
2. **Energy:** Modeling of energy consumption for a simulated population of homes
3. **Savings:** Projection of savings associated with improved compliance

Following data collection, PNNL conducted three stages of analysis on the resulting data set. 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 the potential energy savings, consumer cost savings, and avoided carbon emissions associated with increased code compliance. Together, these findings provide valuable insight on challenges facing energy code implementation and enforcement, 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 Maryland field study data, with the resulting findings presented in Section 3.0 (State Results).

---

[6] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study. The form is similar to those used by the RES*check* compliance software organized with requirements for envelope, mechanical, and lighting listed on separate tabs.
[7] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study

2.3.1 Statistical Analysis

Standard statistical analysis was performed with distributions of each key item plotted by climate zone. 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.

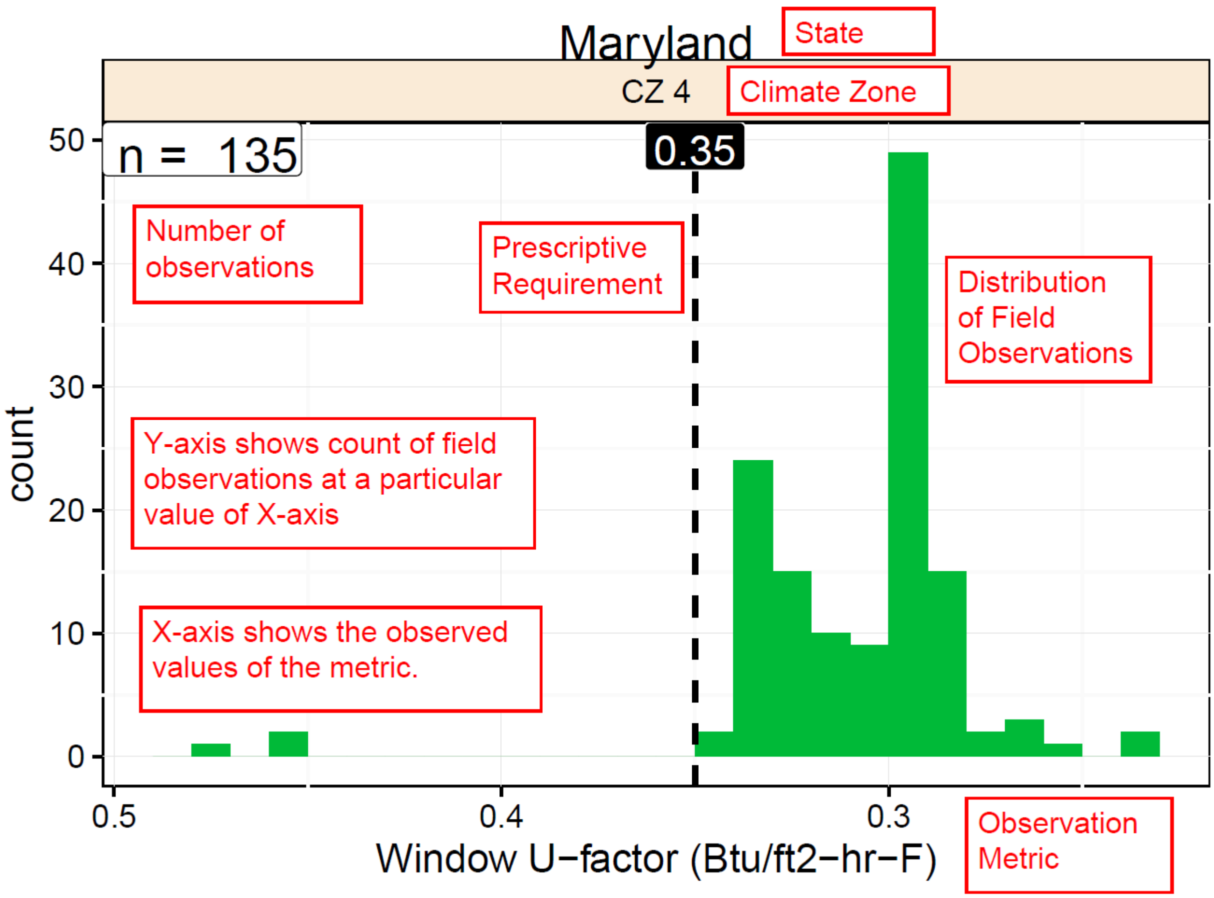

Figure 2.1. Sample Graph

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 climate zone 4 in Maryland is 0.35)—values to the right-hand side of this line are *better than code*. Values to the left-hand side of this line represent areas for improvement.

2.3.2 Energy Analysis

The next phase 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 sufficient 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.

Energy simulation was then conducted using the EnergyPlus™ software.[8] 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 provides perspective on 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.

Further specifics of the energy analysis are available in a TSD (DOE 2016b).[9]

2.3.3 Savings Analysis

To begin the third phase, each of the key items was examined to determine those where a significant number of observed values did not meet the associated code requirement[10]. For these items, additional models were then 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). This was done by individually upgrading each worse-than-code observation to the corresponding *prescriptive* code requirement, resulting in a second set of models (*full compliance*) that could be compared to the first (*as built*). All other components were maintained at the corresponding prescriptive code value, allowing for the savings potential associated with that key item to be evaluated in isolation.

Once the full compliance models were created, additional energy simulation was carried out using EnergyPlus. All variations of observed heating systems and foundation types were included, and annual electric, gas and total EUIs were extracted for each building. For each key item analyzed, the difference in energy use between the *as built* and *full compliance* cases represents the potential energy savings that can theoretically be achieved if all homes met the code minimum. To calculate savings, the differences in energy use calculated for each case are weighted by the corresponding frequency of each observation to arrive at an average energy savings potential for each climate zone. For states with multiple climate zones, potential energy savings for each climate zone are further weighted using construction starts in that

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

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

[10] "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.

zone to obtain the average statewide energy savings potential. State-specific construction volumes and fuel prices are 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 can 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.

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 can be considered statistically significant only at the state level. Other results were identified as of interest, such as analysis based on climate zone level, or reporting of non-key items. While some of these items are visible in the publicly available data set, they should not be considered statistically representative.

2.4.2 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 as 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 (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.

2.4.3 Sampling Substitutions

As is often the case with field-based research, substitutions to the state sampling plan 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 level of construction activity and demographics. DOE approval was required prior to making substitutions.

2.4.4 Site Access

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 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 leakage was modeled separately from the other key items due to limitations in the EnergyPlus™ software used for analysis. It should also be noted that the resulting energy consumption and savings projections are based on modeled data, and not on utility bills or actual home energy usage.

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.

3.0 State Results

3.1 Field Observations

The key items form the basis of the study, and are therefore the focus of this section, followed by a discussion of other findings. A description of how insulation installation quality observations were used to modify certain key item results is also included. (See Section 2.3.1 for a sample graph and explanation of how they should be interpreted.)

3.1.1 Key Items

The Maryland 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. Note that these key items are also the basis of the results presented in the subsequent *energy* and *savings* phases of analysis.

The following key items were found applicable within the state:

1. Envelope tightness (ACH at 50 Pascals)
2. Window SHGC
3. Window U-factor
4. Exterior wall insulation (assembly U-factor)
5. Ceiling insulation (R-value)
6. Lighting (% high-efficacy)
7. Duct tightness (expressed in cfm per 100 ft^2 of conditioned floor area at 25 Pascals)

A variety of foundation types were observed across the state. While foundation insulation was specified as a key item, and the project teams were responsible for collecting the required number of associated data points, the variety resulted in few observations for any one foundation type. For this reason, foundation insulation is not included in this section.

3.1.1.1 Envelope Tightness

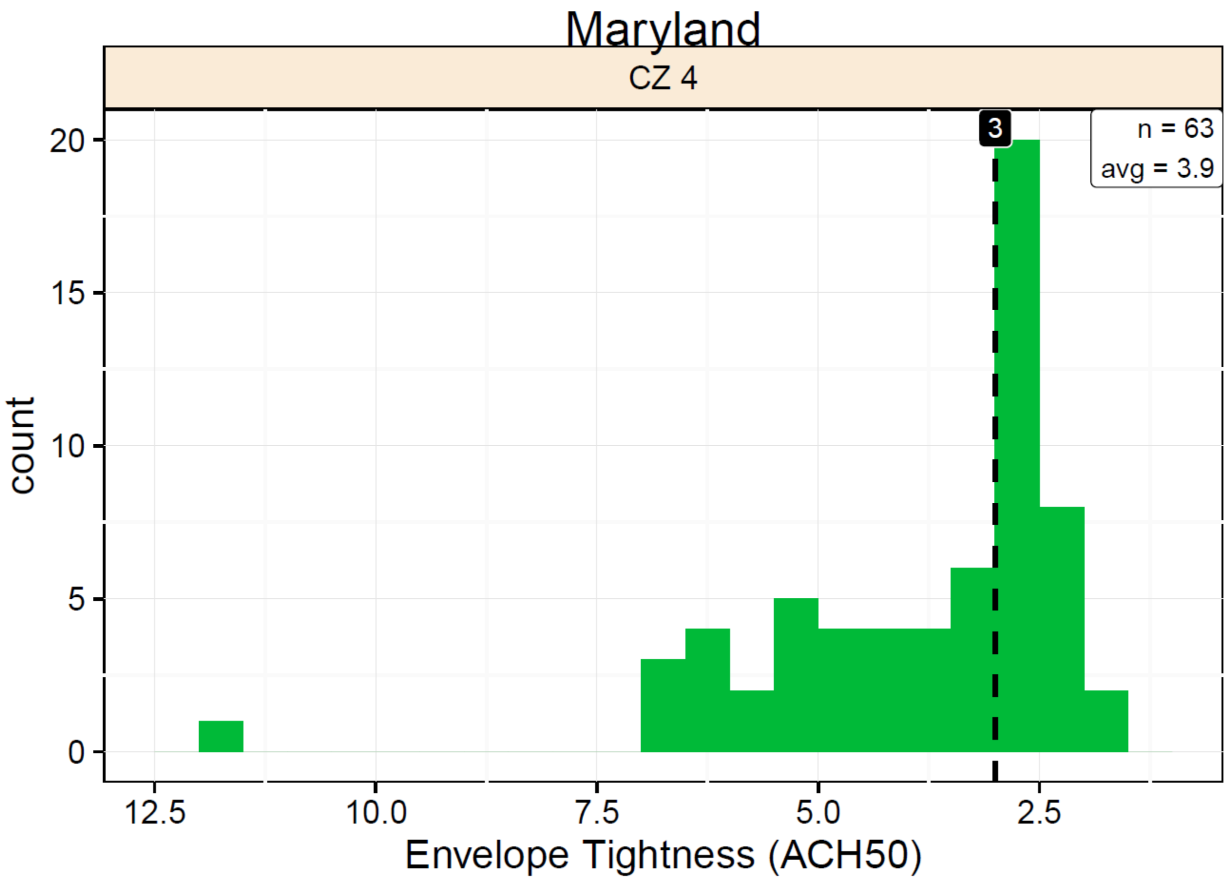

Figure 3.1. Envelope Tightness

- **Requirement**: 3.0 ACH50 (CZ4)
- **Observations:**
  - Number: 63
  - Range: 11.80 to 1.92 ACH50
  - Average: 3.9 ACH50
  - Compliance Rate: 34 of 63 (54%)
- **Interpretations:** Overall, the distribution exhibits higher air leakage than expected based on the current code requirement. Just over half of the observations met or exceeded the prescriptive code requirement, and almost all of the remaining observations were in the 5 to 7 ACH50 range. Reductions in envelope air leakage represent a significant area for improvement in the state, and should be given attention in future training and enforcement.

  Doors, windows and others parts of the thermal envelope were generally observed to be sealed (up to 100% on some specific checklist items). However, these results are from checklist items that are addressed via visual inspection. When comparing these visual results with the actual blower door testing results, it is clear that there can be significant differences in the two ways of evaluating envelope sealing. The visual method and blower door test really address two different aspects of envelope sealing. The visual inspection forces the builder to seal the major trouble spots in a building. According to the project team and industry feedback, following the visual inspections items in the checklist generally results in the range of 5-7 ACH. However, sealing each spot and using the best available product or the best approach to sealing can often mean the difference between compliance and non-compliance via the blower door test. Builders are required to follow the air sealing checklist items in the code, but must also implement more detailed solutions to get an extra tight seal and meet the blower door testing threshold.

The project team also reported that implementation of the ACH requirement has been problematic in townhomes. In some jurisdictions (but not all), code officials allow 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 leakage 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.

3.1.1.2 Window SHGC

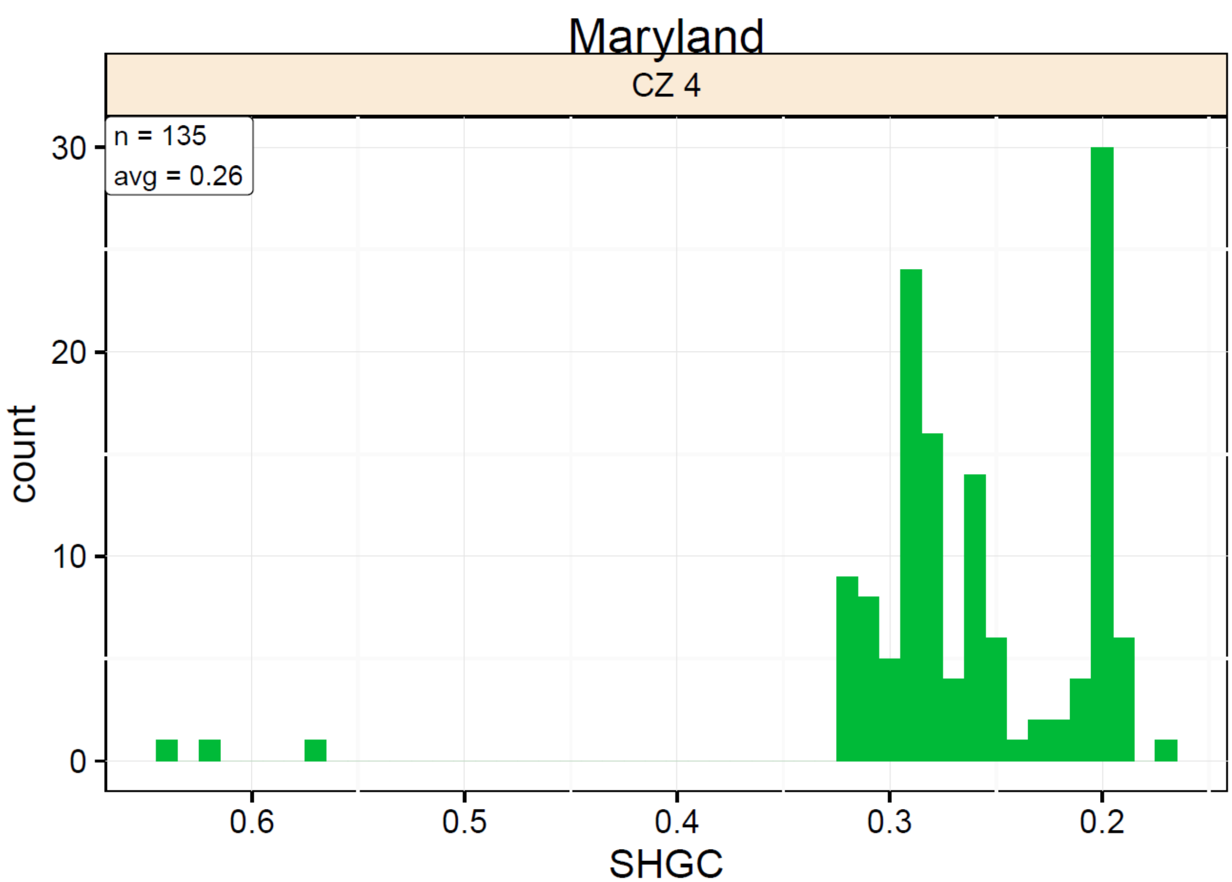

Figure 3.2. Window SHGC

- **Requirement**: NA in Maryland (CZ4)

- **Observations:**
  - **Number**: 135
  - **Range**: 0.64 to 0.17
  - **Average**: 0.26
  - **Compliance Rate**: NA
- **Interpretations**: SHGC values were very consistent, and nearly meet the prescriptive requirement for Climate Zones 1-3. The vast majority of the observations were in the 0.2 to 0.3 SHGC range.

3.1.1.3 Window U-Factor

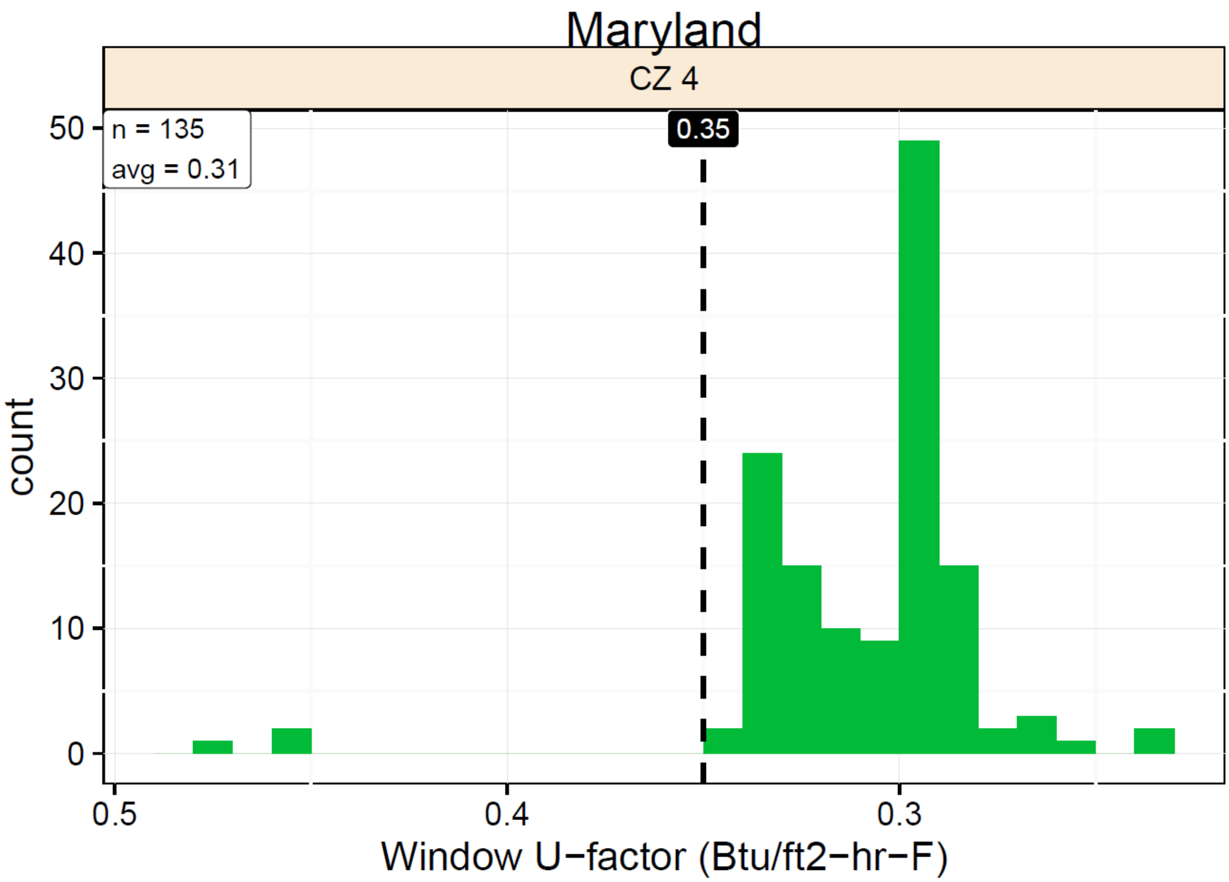

Figure 3.3. Window U-Factor

- **Requirement**: U-0.35 (CZ4)
- **Observations:**
  - **Number**: 135
  - **Range**: 0.48 to 0.24
  - **Average**: 0.31
  - **Compliance Rate**: 132 of 135 (98%)

- **Interpretations**: There is an extremely high rate of compliance for fenestration products in the state. This represents one of the most significant findings of the field study, with nearly all of the observations at or above the code requirement. Window U-factor requirements appear to have been implemented with a high rate of success across the state.

3.1.1.4 Wall Assemblies

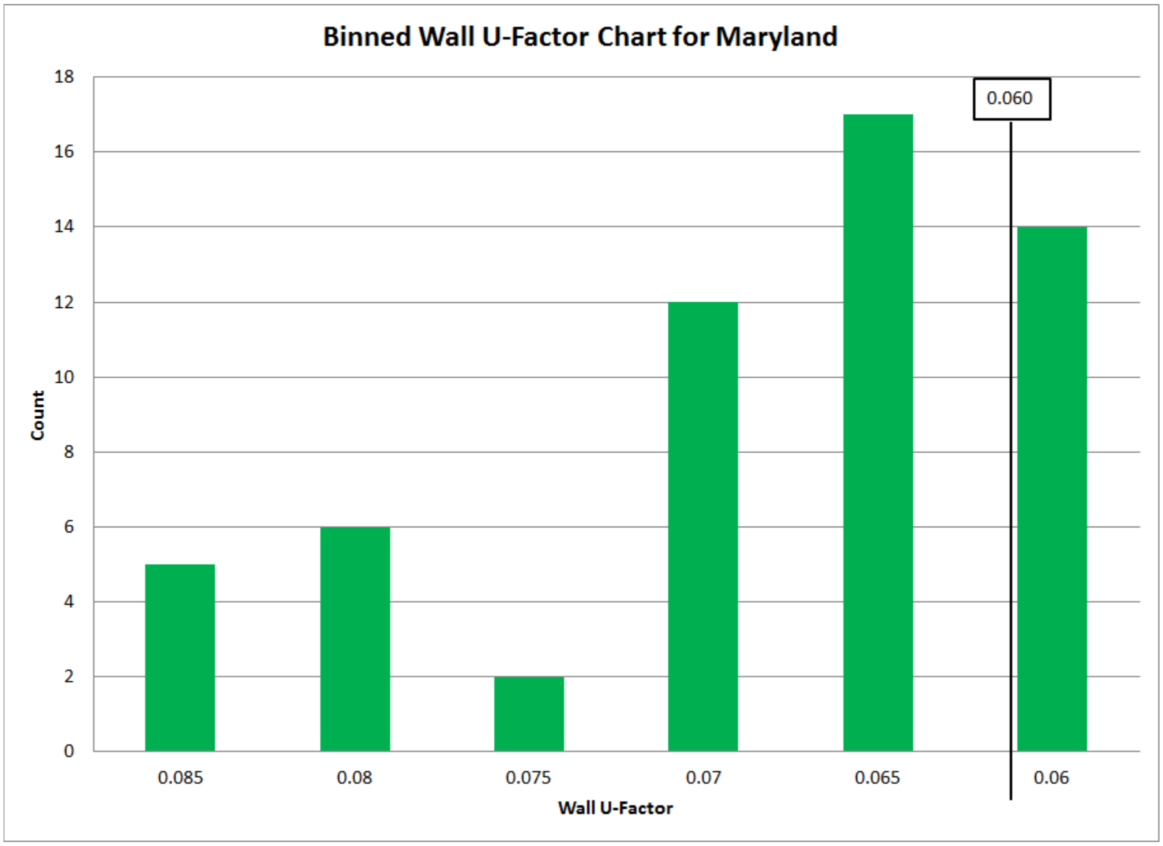

Figure 3.4. Maryland Wall Assembly Performance

- **Requirement**: U-0.060 (CZ4)
- **Observations**:
  - Number: 56
  - Range: 0.083 to 0.048
  - Average: 0.066
  - Compliance Rate: 14 of 56 (25%)
- **Interpretations:** The code allows for two prescriptive options for wall insulation (R-20 or R-13+5 continuous). The energy value of wall insulation 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.

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 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[1]. Interestingly, none of the cavity observations occurred at either of the prescriptive values (R-13 or R-19).

There are a large number of observations (18) of R-15+3, which does not meet the prescriptive (R-13+5) 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.

Insulation quality 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[2]. The majority of these were associated with above-grade walls. A more detailed discussion of insulation installation quality is included at the end of the section (3.1.2).

[1] These observations were reviewed in 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.

[2] Based on the RESNET protocol for insulation grading: http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf

3.1.1.5 Ceilings

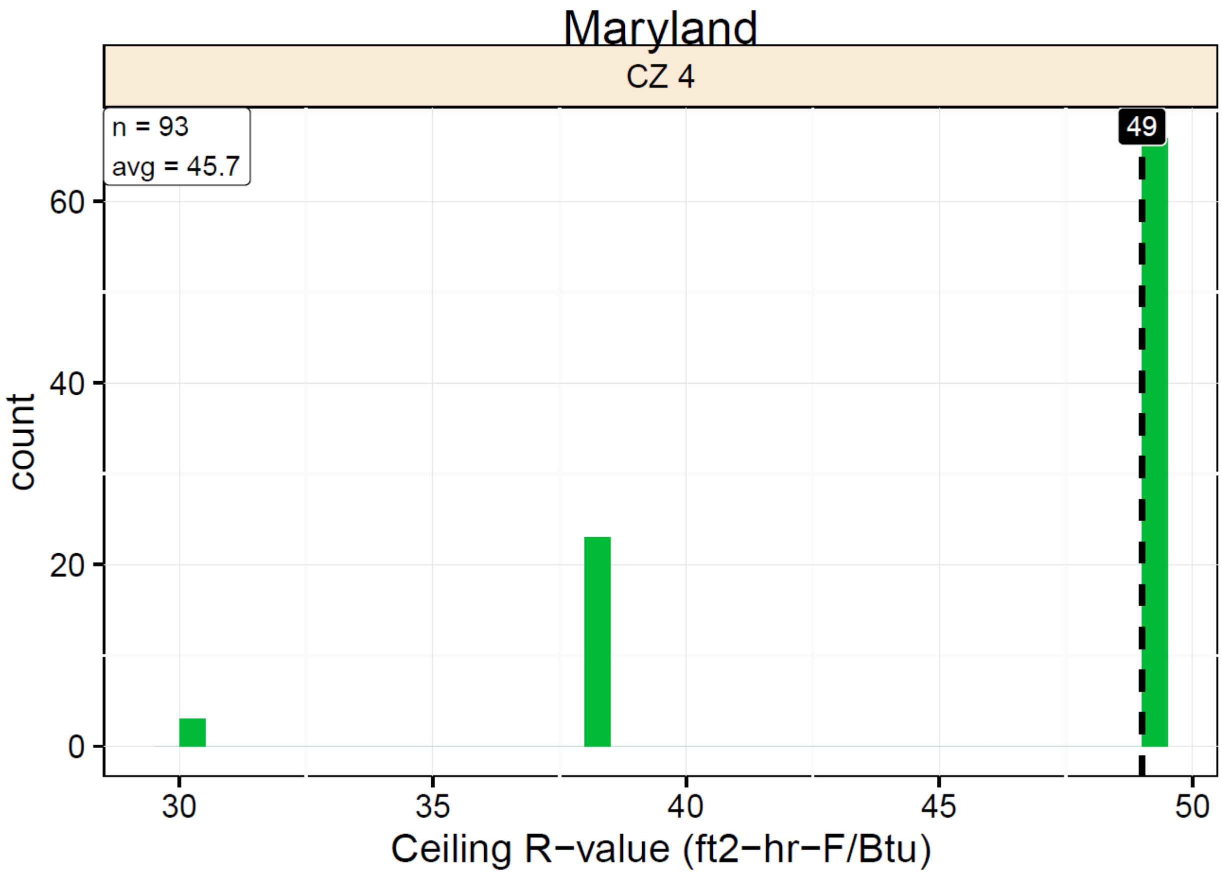

Figure 3.5. Ceiling R-Value

- **Requirement**: R-49 (CZ4)
- **Observations:**
  - Number: 93
  - Range: R-30 to R-49
  - Average: R-45
  - Compliance Rate: 67 of 93 (72%)
- **Interpretations**: The vast majority of observations meet the prescriptive code requirement exactly. The cause of the instances of R-38 and R-30 is unclear, as R-38 is allowed as an alternative in the 2015 IECC if an energy truss is used. R-30 may also be allowed in cases where there is no room for additional insulation, such as a cathedral ceiling. While these specific situations were not recorded[3], the project team noted that about half of the R-38 observations did not appear to meet the prescriptive requirements (i.e., they were not used in combination with an energy truss). The project team also noted that the R-30 observations likely do not meet the prescriptive requirement, as the code allows

[3] The original data collection form did not have specific questions about whether energy trusses or cathedral ceilings were used—this is being reviewed as a potential future addition

only 20% of the roof area to use the cathedral ceiling exception. Based on the observed data and field team feedback, this would indicate that some level of additional training is needed.

3.1.1.6 Lighting

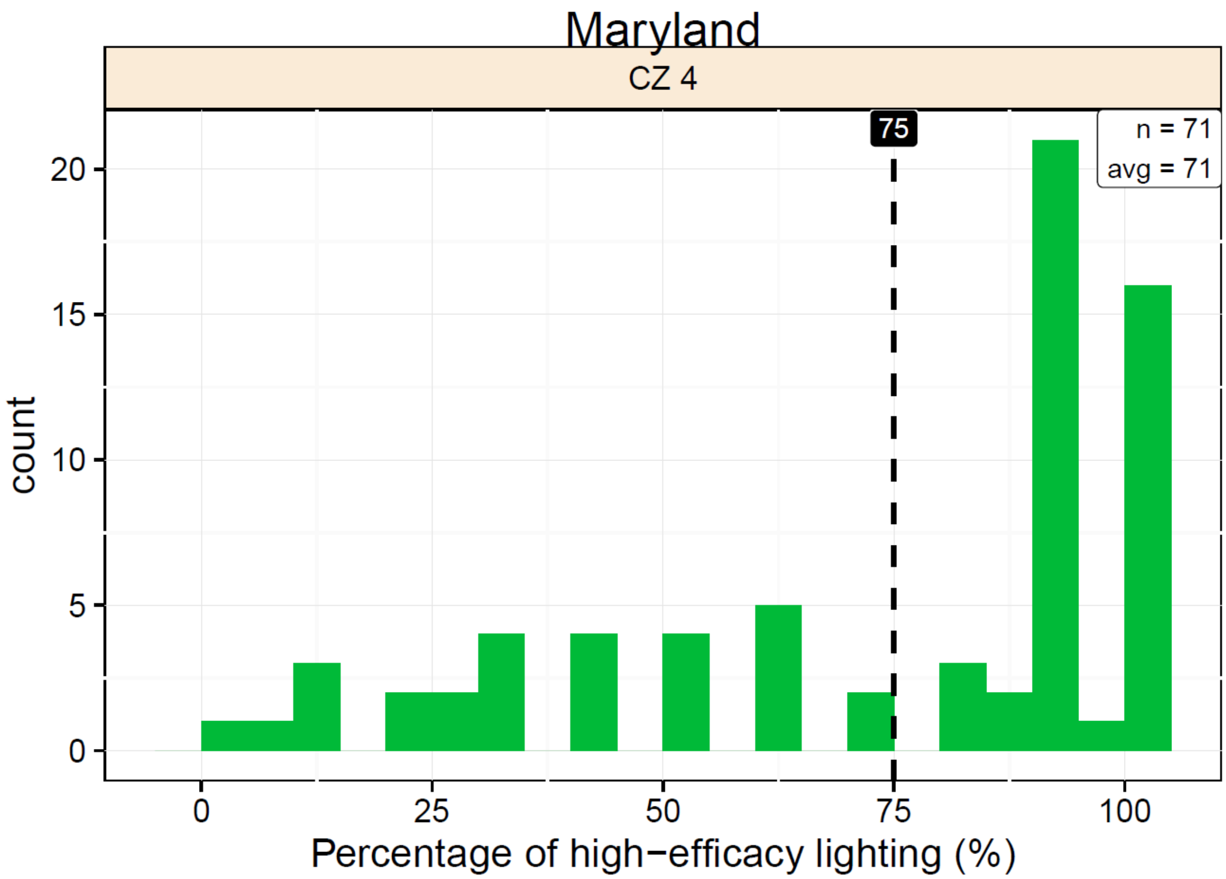

Figure 3.6. High-Efficacy Lighting Percentage

- **Requirement**: 75% high-efficacy
- **Observations:**
  - Number: 71
  - Range: 0 to 100
  - Average: 71
  - Compliance Rate: 43 of 71 (61%)
- **Interpretations**: A little more than half of the field observations were observed to meet the requirement; a much lower number than expected. The most common observations are in the 90-100% range, but there were a significant quantity and wide range of non-compliant observations. This should be considered an area for increased attention in future training and enforcement within the state.

In an attempt the 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:

1. A general lack of understanding of what constitutes an energy efficient lamp.
2. 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.”)
3. Lighting is not clearly specified on plans and the electrician may or may not be familiar with energy code requirements.

3.1.1.7 Duct Tightness

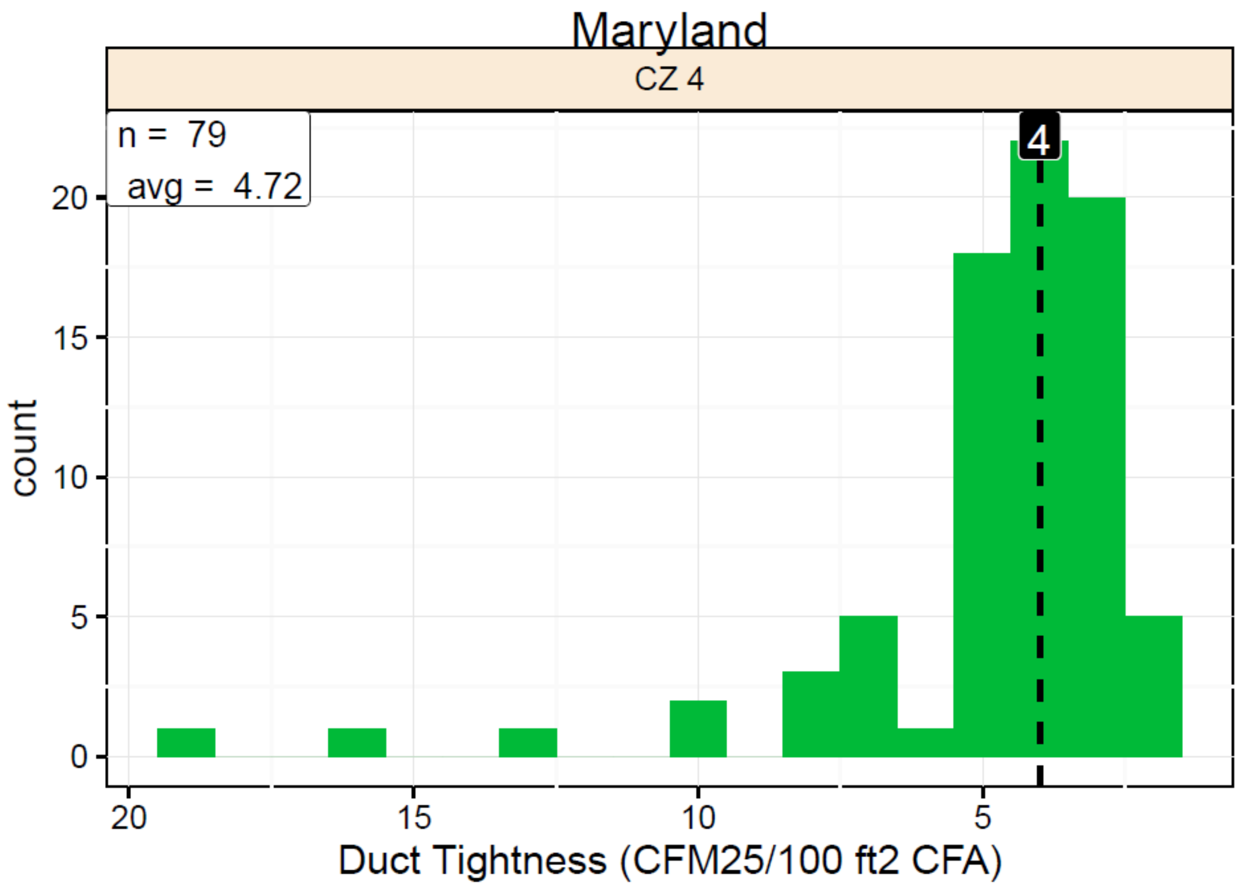

Figure 3.7. Duct Tightness (CFM25/100ft2 CFA)

- **Requirement**: 4.0 CFM25/100 ft^2 CFA
- **Observations:**
  - Number: 59
  - Range: 19.00 to 1.75
  - Average: 4.9 CFM25/100 ft^2 CFA (in unconditioned space); 4.2 for ducts in conditioned space
  - Compliance Rate: 29 of 59 (49%)

- **Interpretations**: Overall the distribution exhibits higher leakage than expected compared to the current code requirement.[4] Just under half of the observations meet the prescriptive requirement, with several of the remaining observations stacked in the range of 4 to 6 CFM25/100 ft^2 CFA, and others scattered with even greater leakage. Reductions in duct leakage represent a significant area for improvement within the state, and should be given increased attention in future training and enforcement.

  Based on visual inspection, ducts were observed as sealed the vast majority of the time (91%). However, these observations yield a significantly different conclusion relative to the duct leakage testing results from the state study. While the code requires ducts, air handlers and filter boxes to be sealed, it does not provide a comprehensive list of inspection points (as it does with envelope air sealing, in comparison), and it is therefore necessary to utilize sealing methods which are adequate in order to meet the required testing threshold. Based on feedback from the project team, some level of duct sealing is often undertaken, however; the products, means and methods elected by the builder or contractor can have a significant impact on overall tested leakage. The code allows use of UL-listed tape for sealing of joints and seams, for example, but industry feedback suggests alternative options, such as mastic, are typically more dependable and will yield a lower test result.

  In Maryland, and under the 2015 IECC, duct tightness testing is *mandatory* (always required), but the associated leakage target is *prescriptive*. Meaning, a home could feasibly comply with higher duct leakage rates by using the performance path (Section 405 or 406), and adding efficiency elsewhere in the building. It is unlikely that the extreme outliers were using this approach, but for the ducts that were barely short of the prescriptive requirement, it may be feasible that these complied using tradeoffs, as allowed by code.

3.1.2 Impact of Insulation Installation Quality

At the start of the project, insulation installation quality was noted as a particular concern among project teams and stakeholders, as it plays an important role in the energy performance of envelope assemblies. Insulation installation quality was therefore collected by the field teams whenever possible, and applied as a *modifier* in the analyses for applicable key items (i.e., ceiling insulation, wall insulation, and foundation insulation). Teams followed the RESNET[5] assessment protocol which has three grades, Grade I being the best quality installation and Grade III being the worst.

Table 3.1 shows the insulation installation quality levels for framed envelope assemblies, as observed in the state. The majority of the observations (233 of 286) were classified as Grade I, indicating that insulation installation quality is generally good.

[4] There were an additional 20 homes in the state sample with ducts located entirely within conditioned space. These leakage rates were not included in the energy analysis, and are therefore omitted from the above Duct Tightness graphic.

[5] See http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf

Table 3.1. Insulation Installation Quality

Assembly	Grade I	Grade II	Grade III	Total Observations
Roof Cavity	86	7	0	**93**
Floor	45	11	1	**57**
Above Grade Wall	33	21	2	**56**
Basement Wall	46	6	2	**54**
Knee Wall	21	3	0	**24**
Crawlspace Wall	2	0	0	**2**

The project team reported common issues with insulation installation quality and air barriers behind bathroom tubs and showers, in particular. In addition, quality of slab edge insulation (although not included on the data collection form for the study) was typically observed as Grade III.

3.1.3 Additional Data Items

The project team collected data on all code requirements within the state as well as other areas 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 the Appendix. The full data set is also available on the DOE Building Energy Codes Program website.[6]

3.1.3.1 Average Home

- Size: 3232 ft^2 and 2.35 stories
- Bedrooms: 3.78

3.1.3.2 Compliance

- The majority of homes were permitted under the 2015 IECC (64%) or 2012 IECC (30%)
- Approximately half of the homes (49%) participated in an above-code program[7]

3.1.3.3 Envelope

- *Profile:*
  - Walls: Majority were wood-framed walls with a mix of 4” (54%) and 6” (46%) studs

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

[7] *All* of the homes which were participating in an above-code program were found to be participating in the ENERGY STAR for Homes program

- Foundations: Mix of basements (53%)[8], slab-on-grade (44%) and crawlspaces (3%)

- *Successes:*
  - Insulation was almost always labeled (99%)
  - IC-rated light fixtures were almost always sealed (99%)
  - Utility penetrations were almost always sealed (98%)
- *Areas for Improvement:*
  - A significant number of attic hatches & doors did not exhibit the required insulation value (26%)
  - Attic access openings were often not sealed (65%)
  - Knee walls were often not sealed (74%)
  - Envelope areas behind bathroom tubs & showers were often not sealed (81%)
  - Proper air sealing was often not provided between the garage and conditioned spaces (83%)

3.1.3.4 Duct & Piping Systems

- *Profile:*
  - Ducts were generally located within conditioned space (percentage of duct system):
    - Supply: 67% (44 homes entirely within conditioned space)
    - Return: 76% (97 homes entirely within conditioned space)
  - About 28% of homes located *supply* ducts entirely within conditioned space
  - About 61% of homes located *return* ducts entirely within conditioned space
  - Duct Insulation (R-value): 92% of all duct insulation observations were R-8 as required by code
  - Pipe Insulation (R-value): 3
- *Successes:*
  - Building cavities were almost never used as ducts (96%)
- *Areas for Improvement:*
  - Air handlers (71%) and filter boxes (57%) were often not sealed

3.1.3.5 HVAC Equipment

- *Profile:*
  - Heating: Mostly gas furnaces with an average efficiency of 93 AFUE. All furnaces observed in the study had an efficiency of 90 AFUE or better.
  - Cooling: Mostly central AC with an average efficiency of 13 SEER
  - Water Heating: Mix of gas (46%) and electric (54%) storage with an average capacity of 62 gallons and average efficiency rating of EF 0.78
  - Ventilation: Majority exhaust-only (89%) or AHU-integrated (9%). Approximately 90% of homes had a dedicated exhaust fan—only 10% relied solely upon the bathroom fan.

[8] Almost all basements observed in the study were conditioned

- *Successes:*
  - Programmable thermostats were almost always installed (99%)
  - User manuals for mechanical systems were provided the vast majority of the time (92%)

3.2 Energy Intensity

In terms of overall energy consumption, homes in Maryland appear to use *more* energy than would be expected relative to homes built to the current minimum state code requirements. The observed data set (as gathered in the field) was compared against the same set of homes meeting prescriptive code requirements. The statewide energy analysis results are shown in Figure 3.8, which compares the weighted average energy consumption of the observed data set to the weighted average consumption based on the state energy code.

Analysis of the collected field data indicates an average regulated EUI (dotted line in Figure 3.8) of approximately 30.49 kBtu/ft^2-yr compared to 27.56 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements (black line in Figure 3.8). This suggests the EUI for a "typical" home in the state is about 10.6% worse than code. Tempering this finding is the fact that Maryland has one of the most stringent residential energy codes in the country.

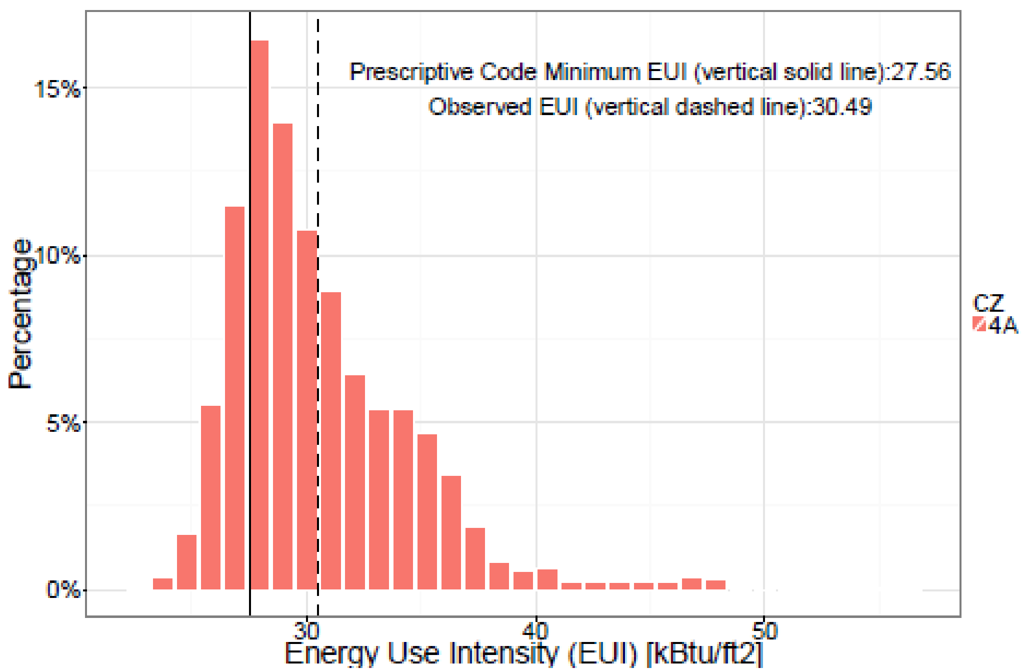

Figure 3.8. Statewide EUI Analysis for Maryland

3.3 Savings Potential

Several key items exhibit the potential for improvement. Those with the greatest potential[9], shown below followed by the percent that did not meet code, were analyzed further to calculate the associated savings

[9] Defined here as those items where more than 15% of observations did not meet the prescriptive code requirement

potential, including energy, cost and carbon savings. For analytical details refer to Section 2.3.3 (Savings Analysis) or the methodology TSD (2016b).

- Envelope Air Leakage (52%),
- Exterior Wall Insulation (75%),
- Lighting (39%),
- Duct Leakage (51%), and
- Ceiling Insulation (28%).

Estimated savings resulting from the analysis are shown below in order of highest to lowest total energy, cost and carbon savings (Table 3.2). As can be seen, there are significant savings opportunities, with the greatest total savings potential associated with these measures. In addition, Table 3.3 shows the total savings and emissions reductions that will accumulate over 5, 10, and 30 years of construction.

Table 3.2. 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 Leakage	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 Leakage	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**

Table 3.3. Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings for Maryland

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
	5yr	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Leakage	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 Leakage	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**	**717,396,885**	**112,035**	**410,795**	**3,473,085**

4.0 Conclusions

The Maryland field study provides an enhanced understanding of statewide code implementation, and suggests that significant savings are available through increased compliance. At the time of the study, the state had recently adopted the 2015 IECC without amendment, making it one of the first to implement the current model code, and creating a unique opportunity for study.

Significant savings can be achieved in the state through increased compliance with the Maryland energy code. Potential statewide annual energy savings are 93,341 MMBtu, which equates to $1,542,789 in cost savings, and emission reductions of 7,469 MT CO2e. Over a 30-year period, these impacts grow to 43,400,000 MMBtu, $717 million, and over 3,470,000 MT CO2e in avoided emissions.

Several key measures directly contribute to these savings, and should be targeted through future education, training and outreach activities. The savings associated with each are:

Table 4.1. Annual Statewide Savings Potential in Maryland

Key Measure		Annual Savings		
		Energy (MMBtu)	**Cost ($)**	**Carbon (MT CO2e)**
1	Envelope Air Leakage	53,868	754,946	3,569
2	Exterior Wall Insulation	25,230	401,480	1,934
3	Lighting	3,566	195,378	1,032
4	Duct Leakage	8,108	146,619	718
5	Ceiling Insulation	2,569	44,366	216
Total		**93,341**	**1,542,789**	**7,469**

The average home in Maryland uses about 11% more energy than a home exactly meeting the state energy code. In terms of particular measures, fenestration (U-factor & SHGC) was better than code across the board, with the average window exceeding the requirement of any U.S. climate zone. Other measures had varying degrees of savings potential.

5.0 References

Census Bureau. 2016. Censtats Building Permits Database. http://censtats.census.gov/

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*, available at http://www.energycodes.gov/development

DOE Building Energy Codes Program's residential field study website is available at https://www.energycodes.gov/compliance/residential-energy-code-field-study (accessed August 1, 2016).

DOE/PNNL 2016a. "Protocol for Measuring Residential Energy Code Compliance." Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study

DOE/PNNL 2016b. "Residential Energy Code Field Study Data Analysis: Technical Support Document." Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study

EnergyPlus. https://energyplus.net/.

Newport Partners LLC residential field study website is available at http://newportpartnersllc.com/projects/residential_energy_efficiency.html (accessed August 1, 2016).

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

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. 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**

B.2 Substitutions

In the 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.

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

- Size (n=206): 3232 ft^2
- Number of Stories (n=206): 2.35
- Number of Bedrooms (n=206): 3.78

Table C.1. Conditioned Floor Area (ft^2)

Conditioned Floor Area (ft^2)	< 1000	1000 to 1999	2000 to 2999	3000 to 3999	4000+
Percentage	0%	17%	42%	17%	24%

Table C.2. Number of Stories

No. of Stories	1	2	3	4+
Percentage	2%	48%	47%	4%

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

Table C.3. Number of Bedrooms

No. of Bedrooms	1	2	3	4	5+
Percentage	0%	0%	36%	52%	12%

C.1.1.2 Wall Profile

- **Framing Type (n=164):**
  - *All* were framed construction (100%)
- **Framing Material (n=97):**
  - Wood (99%)
  - Steel (1%)
- **Framing Depth (n=97):**
  - 4” (54%)
  - 6” (46%)
- **Type of Wall Insulation (n=56)**
  - Cavity Only (54%)
  - Cavity + Continuous (46%)
  - Continuous Only (0%)

C.1.1.3 Foundation Profile

- **Foundation Type (n=205):**
  - Basement (53%)
  - Slab on Grade (44%)
  - Crawlspace (3%)
- **Basement Type (n=104):**
  - Conditioned (98%)
  - Unconditioned (2%)

C.1.1.4 Other

- *None* had a pool or spa (n=157)
- *None* had a sunroom (n=158)

C.1.1.5 Builder Profile

- Average number of Homes Built Annually (n=206): 125 homes

Table C.4. Number of Homes Built by Builder (annually)

No. of Homes per Year	< 10	10 to 50	50 to 99	100+
Percentage	12%	19%	17%	52%

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:

C.1.2.1 Energy Code Used (n=206):

Table C.5. Energy Code Used

Energy Code	2009 IECC	2012 IECC	2015 IECC
Percentage	6%	30%	64%

- **Was the home participating in an above-code program (n=156)?**
  - Yes (49%)*
  - No (51%)

  * All of these homes reported participation in the ENERGY STAR for Homes program[1]

C.1.3 Envelope

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

C.1.3.1 Insulation Labels

- **Was insulation labeled (n=73)?**
  - Yes (99%)
  - No (1%)

C.1.3.2 Ceilings

- **Did the attic hatch/door exhibit the correct insulation value (n=69)?**
  - Yes (26%)
  - No (74%)

[1] *See* https://www.energystar.gov/index.cfm?c=new_homes.hm_index

C.1.3.3 Air Sealing[1]

The following questions indicate whether sealing was completed in accordance with the checklist and associated code requirements:

- **Thermal envelope (n=64)?**
  - *All* responses were reported to comply (100%)
- **Fenestration (n=64)?**
  - *All* responses were reported to comply (100%)
- **Openings around windows and doors (n=64)?**
  - *All* responses were reported to comply (100%)
- **Utility penetrations (n=65)?**
  - Yes (98%)
  - No (2%)
- **Dropped ceilings (n=60)?[2]**
  - Yes (88%)
  - No (12%)
- **Knee walls (n=35)?**
  - Yes (74%)
  - No (26%)
- **Sealing between the garage and conditioned spaces (n=65)?**
  - Yes (83%)
  - No (17%)
- **Garage walls and ceilings (n=66)?**
  - Yes (86%)
  - No (14%)
- **Tubs and showers (n=64)?**
  - Yes (81%)
  - No (19%)
- **Common walls (n=31)?**
  - *All* responses were reported to comply (100%)
- **Attic access openings (n=74)?**
  - Yes (65%)

[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.

- No (35%)

- **Rim joists (n=75)?**
  - *All* responses were reported to comply (100%)
- **Other sources of infiltration (n=64)?**
  - *All* responses were reported to comply (100%)
- **IC-rated light fixtures (n=145)?**
  - Yes (99%)
  - No (1%)

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:

C.1.4.1 System Profile

- **Duct Location in Conditioned Space (percentage):**
  - *Supply* (n=159): 67% (44 homes with systems located entirely within conditioned space)
  - *Return* (n=159): 76% (97 homes with systems located entirely within conditioned space)
- **Duct Insulation (R-value):**
  - *Supply* (n=138): 7.5
  - *Return* (n=132): 7.4
- **Ducts in Attics (R-value):**
  - *Supply* (n=127): 7.4 (9 homes observed to have no attic duct insulation)
  - *Return* (n=124): 7.4 (9 homes observed to have no attic duct insulation)
- **Pipe Insulation (R-value):**
  - *All* responses a value of R3 (n=55)
- **Were building cavities used as ducts (n=79)?**
  - Yes (4%)
  - No (96%)
- **Were air ducts sealed (n=86)?**
  - Yes (91%)
  - No (9%)
- **Were air handlers sealed (n=156)?**
  - Yes (71%)
  - No (29%)
- **Were filter boxes sealed (n=157)?**

- Yes (57%)
- No (43%)

C.1.5 HVAC Equipment

The following represents an average profile of observed HVAC equipment, followed by:

C.1.5.1 Heating

- **Fuel Source (n=159):**
  - Gas (86%)
  - Electricity (14%)
- **System Type (n=159):**
  - Furnace (86%)
  - Heat Pump (13%)
  - Electric Resistance (1%)
- **Average System Capacity (n=150):**
  - Furnace : 64,000 Btu/hr
  - Heat Pump: 32,500 Btu/hr
- **Average System Efficiency (n=152):**
  - Furnace: 93 AFUE (*all* observed furnaces had an efficiency of 90 AFUE or better)
  - Heat Pump: 8 HSPF

C.1.5.2 Cooling

- **System Type (n=118):**
  - Central AC (88%)
  - Heat Pump (12%)
- **Average System Capacity (n=71):**
  - Central AC: 32,000 Btu/hr
  - Heat Pump: 25,800 Btu/hr
- **Average System Efficiency (n=70):**
  - Central AC: 13.2 SEER
  - Heat Pump: 13.0 SEER

C.1.5.3 Water Heating

- **Fuel Source (n=104):**
  - Gas (46%)

- Electric (54%)

- **System Type (n=103):**
  - Storage (99%)
  - Tankless (1%)
- **System Capacity (n=99):**
  - Average Storage: 62 gallons (observations ranged from 50 to 80 gallons)

Table C.6. Water Heating System Storage Capacity Distribution

Capacity	< 50 gal	50-59 gal	60-69 gal	70-79 gal	80-89 gal	90+ gal
Percentage	0%	49%	13%	17%	20%	0%

- **Average System Efficiency (n=101):**
  - Electric Storage: EF 0.90
  - Gas Storage: EF 0.65
  - Gas Tankless: EF 0.94

C.1.5.4 Ventilation

- **System Type (n=79):**
  - Exhaust Only (89%)
  - AHU-Integrated (9%)
  - Standalone ERV/HRV (1%)
  - Standalone ERV (1%)
- **Exhaust Fan Type (n=70):**
  - Dedicated Exhaust (90%)
  - Bathroom Fan (10%)

C.1.5.5 Other

- **Were mechanical manuals provided?**
  - Yes (92%)
  - No (8%)
- **Was a programmable thermostat installed?**
  - Yes (99%)
  - No (1%)

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

U.S. DEPARTMENT OF
ENERGY