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Tennessee Residential Energy Code Field Study: Baseline Report

April 2021

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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 Tennessee identified opportunities to reduce homeowner utility bills in residential single-family new construction by increasing compliance with the state energy code. The study was initiated in September 2017 and continued through July 2018. During this period, research teams visited 138 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 $2.5 million in potential annual savings to Tennessee homeowners that could result from increased code compliance.

Methodology

The project team was led by the Southeast Energy Efficiency Alliance (SEEA). 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.

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.

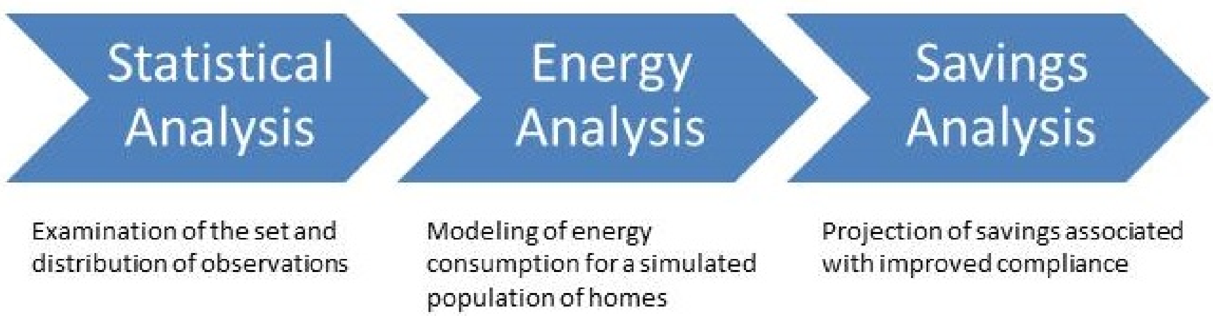

Figure ES.1. Stages of Analysis Applied in the Study

Results

The key items with the greatest potential for savings in Tennessee are presented in Table ES.1. The estimates presented in the table represent the savings potential 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 and training initiatives. In particular, there are significant savings opportunities for wall and ceiling insulation through improved insulation installation quality (IIQ).

Table ES.1. Estimated Annual Statewide Savings Potential

Measure	**Total Energy Savings Potential** (MMBtu)	**Total Energy Cost Savings Potential** ($)	**Total State Emissions Reduction Potential** (MT CO2e)
Exterior Wall Insulation	43,032	904,664	34,119
Ceiling Insulation	27,068	588,867	22,810
Lighting	11,805	427,468	21,557
Envelope Air Tightness	12,561	247,035	8,800
Duct Leakage	7,653	184,062	7,644
Foundation Insulation	10,367	179,403	5,598
Window SHGC	1,160	21,407	717
TOTAL	**113,646 MMBtu**	**$2,552,905**	**101,245 MT CO2e**

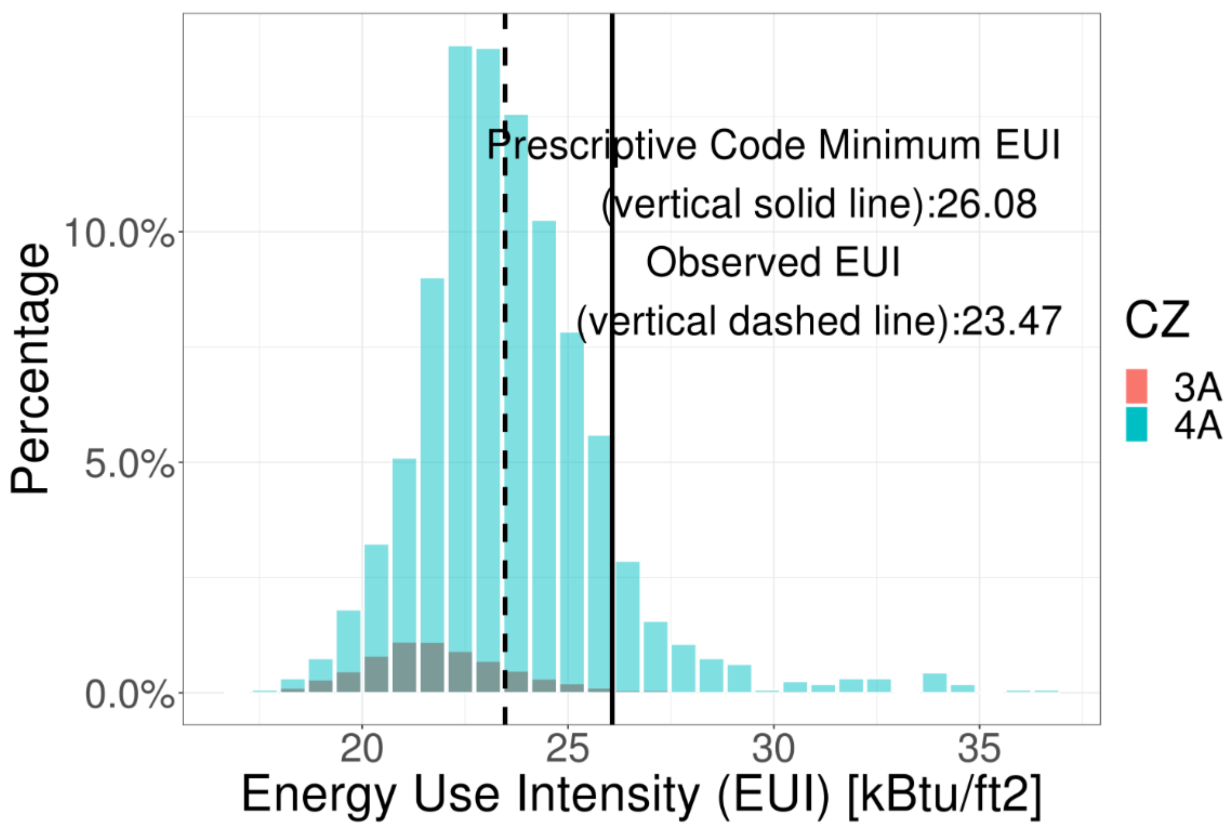

Figure ES.2. Modeled Distribution of Regulated EUI (kBtu/ft^2/year)

In terms of overall energy consumption, the analysis shows that homes within the state use *less* 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 23.47 kBtu/ft^2-yr statewide compared to 26.08 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 10% better than code.

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 Tennessee project team (with their affiliations during the project time period):

- Lauren Westmoreland, *Southeast Energy Efficiency Alliance (SEEA)*
- William Bryan, *SEEA*
- Sareena Nagpal, *SEEA*
- Bourke Reeve, *Southface*
- Brad Turner, *Southface*
- Chris North, *Southface*
- Mike Barcik, *Southface*

Southeast Energy Efficiency Alliance (SEEA)

The Southeast Energy Efficiency Alliance (SEEA) is one of six regional energy efficiency organizations in the United States working to transform the energy efficiency marketplace through collaborative public policy, thought leadership, outreach programs, and technical advisory services. SEEA promotes energy efficiency as a catalyst for economic growth, workforce development and energy security across eleven southeastern states. These states include Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Virginia. For additional information, visit http://www.seealliance.org.

Southface

Since 1978, Southface Energy Institute has provided technical assistance to homeowners, builders, remodelers, architects, developers, utilities and others in the building industry. Southface has expertise in building science, energy efficiency and green design for new and existing buildings including single-family homes, multifamily buildings and commercial structures. Southface is a 501(c)(3) nonprofit organization headquartered in Atlanta, Georgia, with affiliated support throughout the southeast region. Southface develops and manages local, regional and national programs to promote sustainable homes, workplaces and communities. See more at http://www.southface.org/.

Acronyms and Abbreviations

ACH	air changes per hour
AHU	air handling unit
Btu	British thermal unit
cfm	cubic feet per minute
CFA	conditioned floor area
CZ	climate zone
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
ERV	Energy Recovery Ventilator
EUI	energy use intensity
ICC	International Code Council
IECC	International Energy Conservation Code
IIQ	insulation installation quality
kBtu	thousand British thermal units
MMBtu	million British thermal units
NA	not applicable
PNNL	Pacific Northwest National Laboratory
RESNET	Residential Energy Services Network
SEEA	Southeast Energy Efficiency Alliance
SHGC	solar heat gain coefficient
TN	Tennessee

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1.0 Introduction

A research project in the state of Tennessee 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 and training activities, as well as catalyze future investments in compliance improvement programs.

The Tennessee field study was initiated in September 2017 and continued through July 2018. During this period, research teams visited 138 homes across the state during various stages of construction. At the time of the study, the state code was an amended version of the 2009 International Energy Conservation Code (IECC)[1]. The study methodology, data analysis and resulting findings are presented throughout this report.

1.1 Background

This project was built upon the U.S. Department of Energy's (DOE) field study, "Strategies to Increase Residential Energy Code Compliance Rates and Measure Results".[2] The purpose of this study is to gather field data on energy code measures, as installed and observed in actual homes and through the subsequent analysis to identify trends and issues, which eventually can inform energy code training and other compliance-improvement programs.

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. [3,4] 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 overall DOE interest in compliance is available on the DOE Building Energy Codes Program website.[5]

1.2 Project Team

The Tennessee project was led by the Southeast Energy Efficiency Alliance (SEEA), with field data collected by Southface. 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.

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[1] Available at https://publications.tnsosfiles.com/rules/0780/0780-02/0780-02-23.20170202.pdf
2 Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study.
[3] *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.
[4] Available at http://www.energycodes.gov/adoption/states.
[5] Available at https://www.energycodes.gov/compliance.

1.3 Stakeholder Interests

The project started with the formation of a stakeholder group comprised of interested and affected parties within the state. 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 and generate additional savings. The field study is aimed specifically at providing a strong, empirically-based case for such utility investment.

2.0 Methodology

2.1 Overview

The Tennessee field study was based on a methodology developed by DOE to identify savings opportunities associated with increased energy code compliance. This methodology involves gathering field data on energy code measures, as installed and observed in actual homes. In the subsequent analysis, trends and issues are identified, which can help to inform energy code training and other compliance improvement programs.

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**
- **Data 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)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.

The following sections describe how the methodology was implemented as part of the Tennessee study, including sampling, data collection, and resulting data analysis. More information on the DOE data

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[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.

collection and analysis methodologies 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 for Tennessee 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, known as a proportional random sample, was 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).

An initial sample plan was first developed by PNNL, and then vetted by stakeholders within the state. Special considerations were discussed with stakeholders, such as state-specific construction practices or systematic differences across county 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 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.

2.2.2.1 Data Collection Form

The field teams relied on a data collection form customized to the *mandatory* and *prescriptive* requirements of Tennessee's energy conservation code. The final Tennessee data collection form is available in spreadsheet format on the DOE Building Energy Codes Program website.[5] The form included all energy code requirements (i.e., not just the 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 leakage test on every home where such tests could be conducted, using RESNET[6] protocols.

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[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] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study and based on the forms typically used by the RES*check* compliance software. Tennessee used the 2009 IECC data collection form.
[6] See http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf.

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 (IIQ) 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 the 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 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 Analysis:** Examination of the data set and distribution of observations for individual measures
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 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 field study data, with the resulting state-level findings presented in Section 3.0, State Results.

[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.

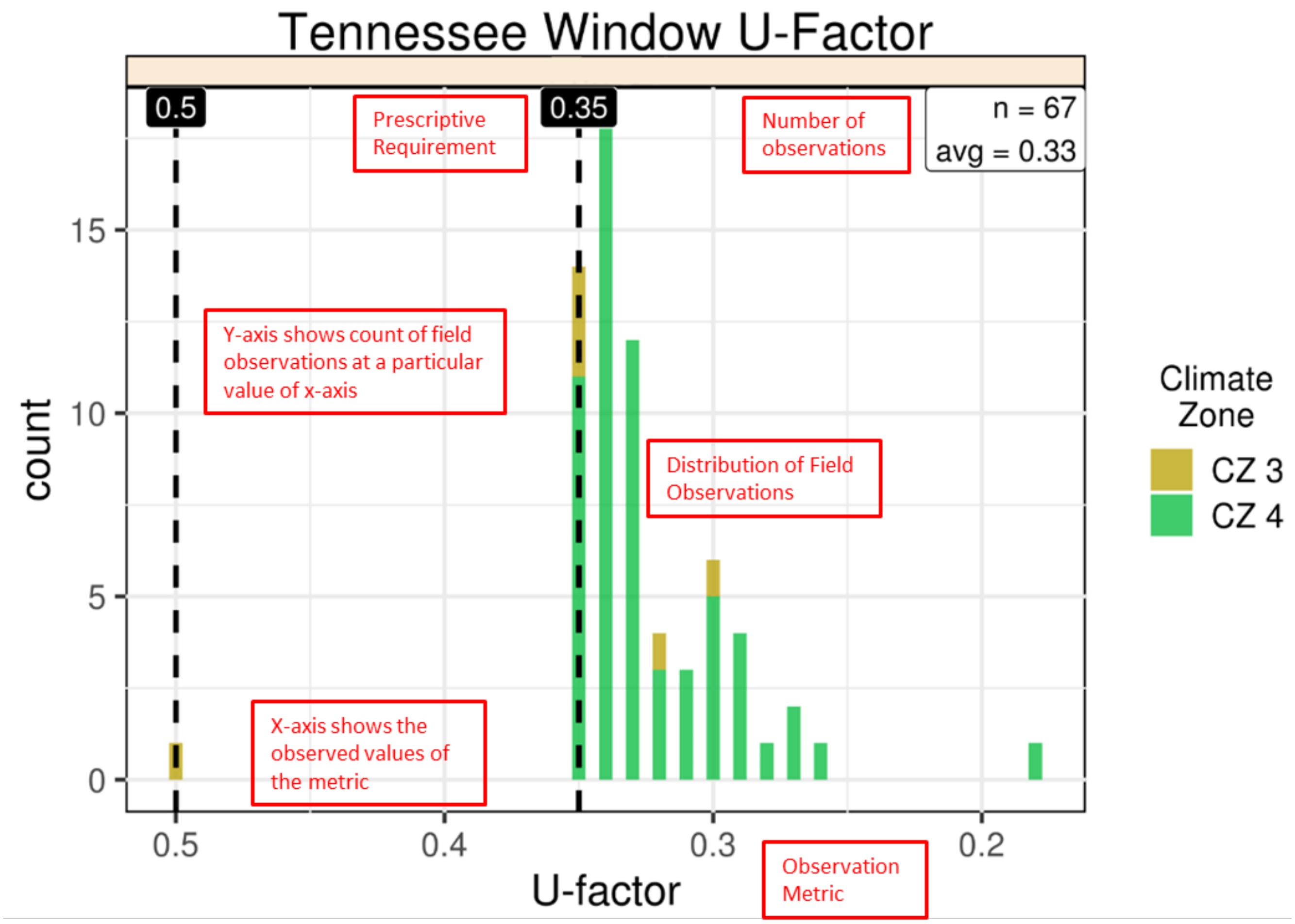

Figure 2.1. Sample Graph

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—values to the right-hand side of this line are *better than code*. Values to the left-hand side 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 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.[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 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).[9]

2.3.3 Savings Analysis

To begin the third phase, each of the key items was examined individually to determine which had any positive number of observed values that did not meet the associated code requirement[10]. 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). 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 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 for each climate zone. Potential energy savings for each climate zone were further weighted using construction starts in that zone to obtain the average statewide energy

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

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

[10] Tennessee was one of the first states evaluated where any observation that did not meet the associated code requirement was used to trigger calculation of measure level savings. In previous studies for other states, the number of observations that did not meet the associated code requirement had to be at least 15% to trigger the calculation of measure level savings.

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 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 leakage 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 potential) are statistically significant only at the state level. Other results, such as analysis based on climate zone level, reporting of non-key items (e.g., gas furnace efficiency), or further stratifications of the public data set 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 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 characteristics such as the level of construction activity and general demographics. More information on the sampling plan and any state-specific substitutions are 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 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. Tennessee is comprised of two climate zones; zone 3 (CZ3) and zone 4 (CZ4). A discussion of other findings is also covered in the section, including of how certain observations, such as insulation installation quality, are used to modify key item results. (See Section 2.3.1 for a sample graph and explanation of how they should be interpreted.)

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. 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)

Two-thirds of the foundation observations were slabs, making slabs the predominant foundation type. There were also 17 floor (over vented crawlspace or unheated basement), 7 unvented crawlspace, and 1 basement wall observations. Due to the fact there is only one basement wall observation, it is not included as a graph. The one basement wall observation did not meet the code requirement.

3.1.1.1 Envelope Tightness

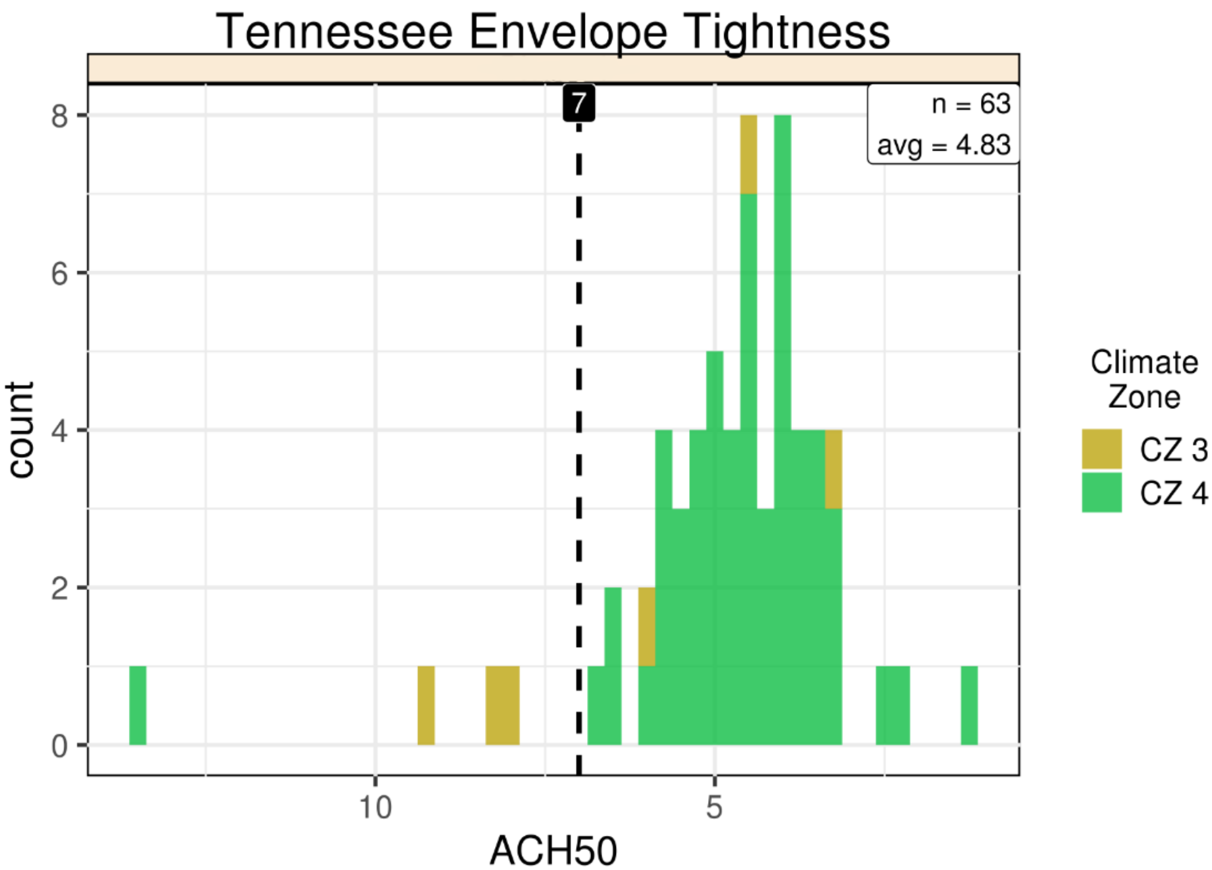

Figure 3.1. Envelope Tightness for Tennessee

Table 3.1. Tennessee Envelope Tightness

Climate Zone	CZ3	CZ4	Statewide
Number	6	57	63
Range	9.2 to 3.2	13.5 to 1.4	13.5 to 1.4
Average	6.48	4.65	4.83
Requirement	7	7	7
Compliance Rate	3 of 6 (50%)	56 of 57 (98%)	60 of 63 (95%)

- **Interpretations:**
  - The majority (95%) of observations met the requirement. There is some room for improvement in CZ 3, but the number of observations is small.

3.1.1.2 Window SHGC

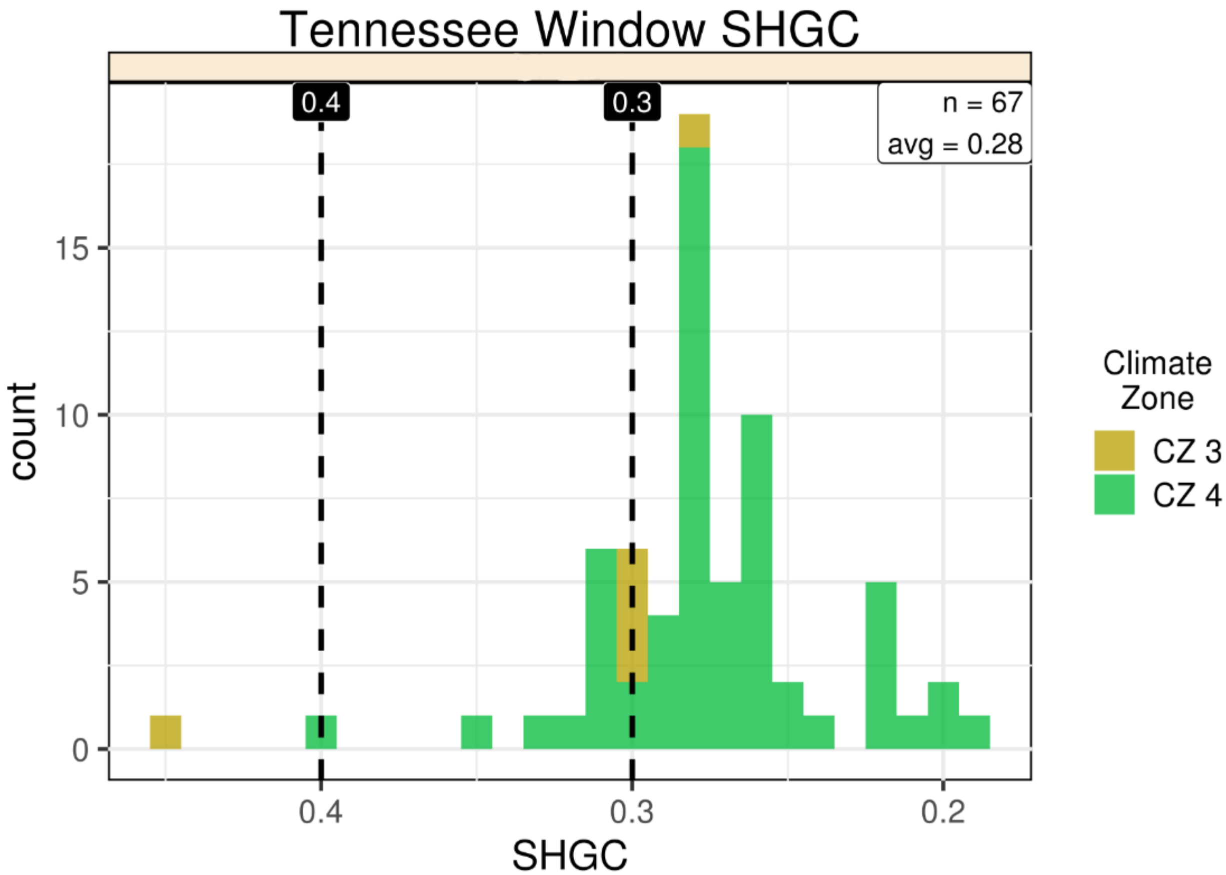

Figure 3.2. Window SHGC for Tennessee

Table 3.2. Tennessee Window SHGC

Climate Zone	CZ3	CZ4	Statewide
Number	6	61	67
Range	0.45 to 0.28	0.40 to 0.19	0.45 to 0.19
Average	0.32	0.27	0.28
Requirement	0.40	0.30	Varies by CZ
Compliance Rate	5 of 6 (83%)	61 of 61 (100%)	66 of 67 (99%)

- **Interpretations:**
  - All but one observation met the prescriptive requirement and most observations significantly exceeded the prescriptive requirement.

3.1.1.3 Window U-Factor

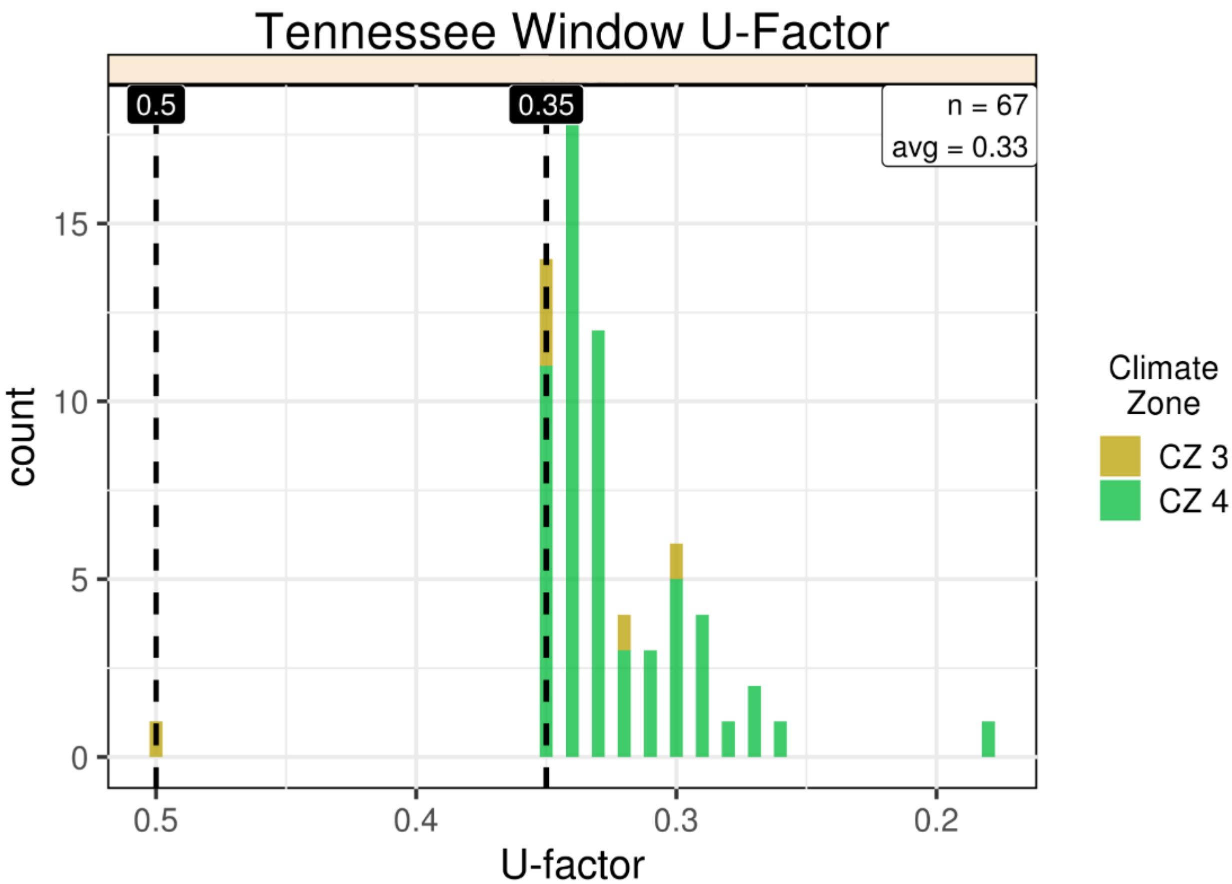

Figure 3.3. Window U-Factor for Tennessee

Table 3.3. Tennessee Window U-Factor

Climate Zone	CZ3	CZ4	Statewide
Number	6	61	67
Range	0.50 to 0.30	0.35 to 0.18	0.50 to 0.18
Average	0.36	0.32	0.33
Requirement	0.5	0.35	Varies by CZ
Compliance Rate	6 of 6 (100%)	61 of 61 (100%)	67 of 67 (100%)

- **Interpretations:**
  - Window U-factor requirements appear to have been implemented with a high rate of success across the state, with all observations meeting the prescriptive requirement.

3.1.1.4 Wall Insulation

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

Figure 3.4 represents the distribution of observed values for wall cavity insulation.

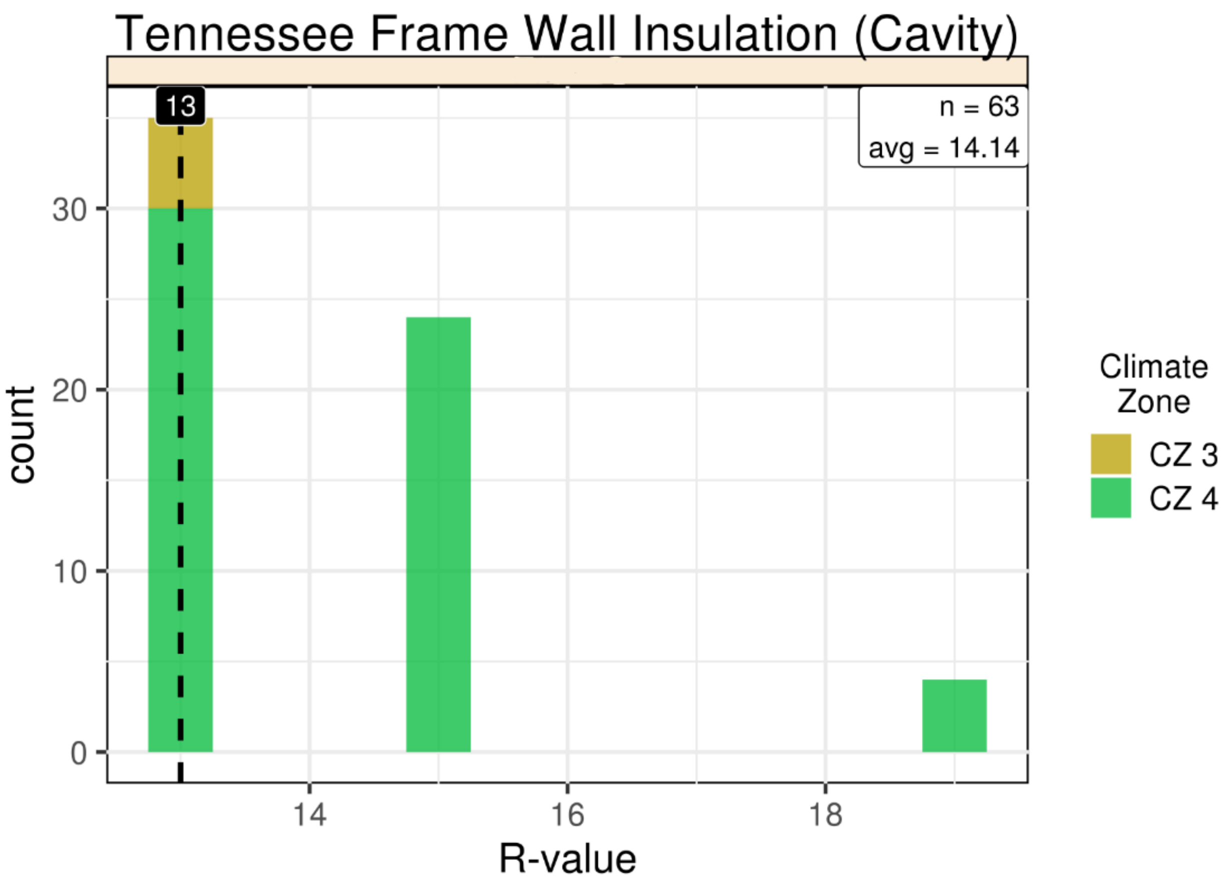

Figure 3.4. Frame Wall R-Value (Cavity) for Tennessee

Table 3.4. Tennessee Frame Wall R-Value

Climate Zone	CZ3	CZ4	Statewide
Number	5	58	63
Range	R-13 to R-13	R-13 to R-19	R-13 to R-19
Average	R-13	R-14.2	R-14.1
Requirement	R-13	R-13	R-13
Compliance Rate	5 of 5 (100%)	58 of 58 (100%)	63 of 63 (100%)

While insulation installation quality (IIQ) is not an explicit energy code requirement, at the start of DOE's residential single-family projects[1], it was noted as a particular concern among project teams and

[1] Projects were awarded under a funding opportunity announcement (FOA). See https://www.energycodes.gov/compliance/energy-code-field-studies for details.

stakeholders, as it plays an important role in the energy performance of envelope assemblies. IIQ was therefore collected by the field team whenever possible and applied as a *modifier* in the analyses for applicable key items (i.e., wall insulation, ceiling insulation, and foundation insulation). The team 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 3.5 shows the number and percentage of IIQ observations by grade for above grade wall insulation.

Table 3.5. Tennessee Above Grade Wall IIQ

Above Grade Wall	Grade I	Grade II	Grade III	Total Observations
Observations	7	25	31	**63**
Percentages	11%	40%	49%	**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 Table 3.6. In the graph, observations are binned for clearer presentation based on the most commonly observed combinations.

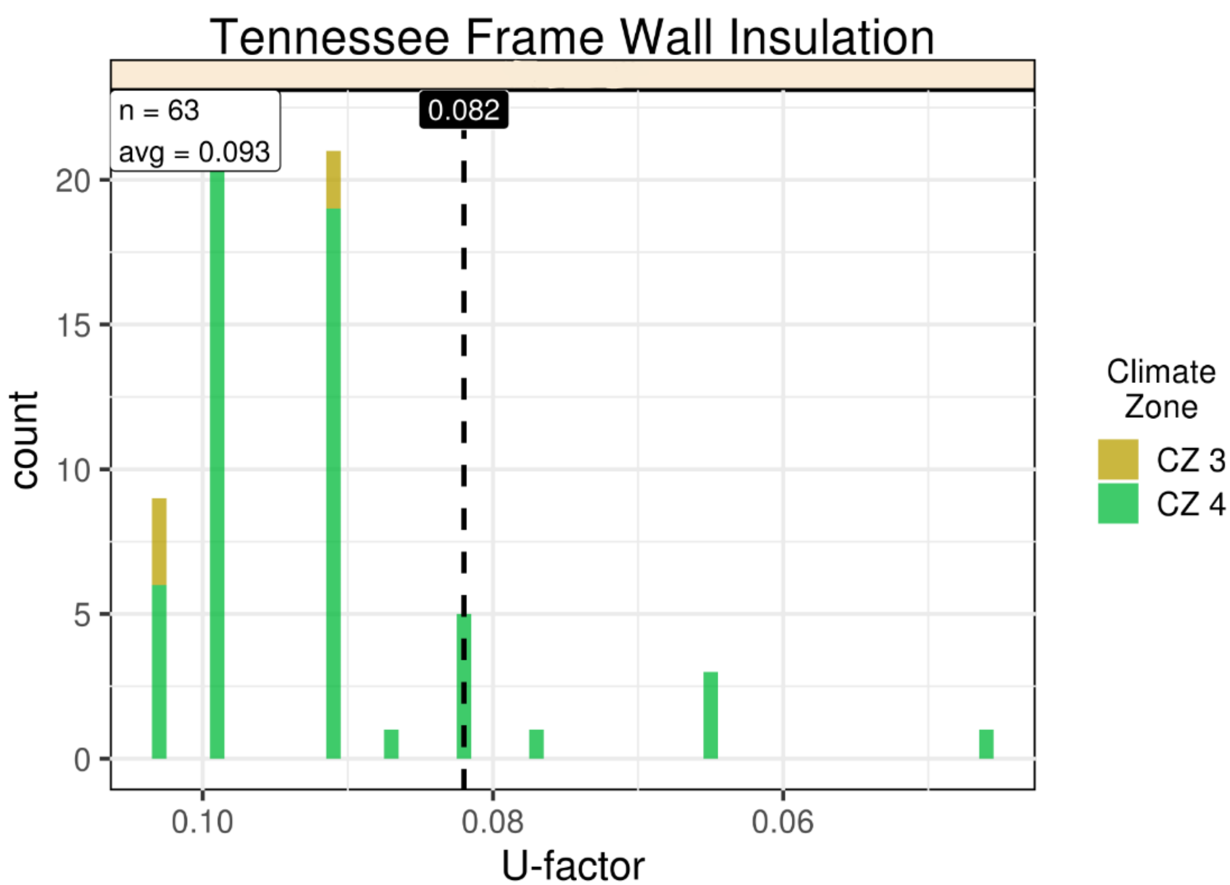

Figure 3.5. Wall U-Factors for Tennessee

[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.

Table 3.6. Tennessee Wall U-Factors

Climate Zone	CZ3	CZ4	Statewide
Number	5	58	63
Range	0.103 to 0.091	0.103 to 0.046	0.103 to 0.046
Average	0.098	0.092	0.093
Requirement	0.082	0.082	0.082
Compliance Rate	0 of 5 (0%)	10 of 58 (17%)	10 of 63 (16%)

- **Interpretations:**
  - Cavity insulation is achieved at a high rate—all observed instances meet or exceed the prescriptive requirement for wall cavity insulation (based on labeled R-value).
  - From an assembly perspective, about 11 percent of observations had an IIQ of Grade I—with the rest rated as Grades II or III (Table 3.5). This leads to an overall U-factor compliance rate of 16%.
  - While cavity insulation appears to be achieved successfully (R-value), the overall assembly performance (U-factor) represents an opportunity for improvement in the state through future education, training and other compliance-support programs.

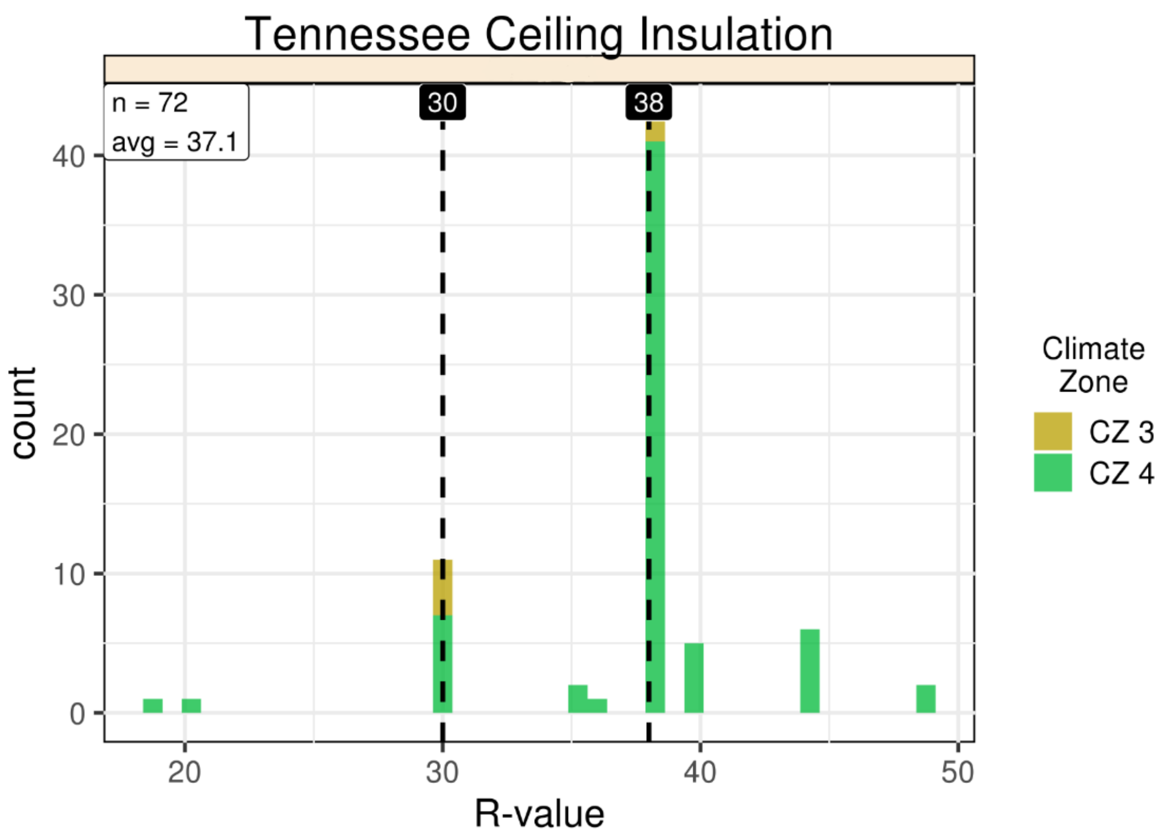

Figure 3.6. Ceiling R-Values for Tennessee

Table 3.7. Tennessee Ceiling R-Value

Climate Zone	CZ3	CZ4	Statewide
Number	6	66	72
Range	R-30 to R-38	R-19 to R-49	R-19 to R-49
Average	R-32.7	R-37.5	R-37.1
Requirement	R-30	R-38	Varies by CZ
Compliance Rate	6 of 6 (100%)	54 of 66 (82%)	60 of 72 (83%)

Table 3.8 shows the number and percentage of IIQ observations by grade for roof cavity insulation.

Table 3.8. Tennessee Roof IIQ

Roof Cavity	Grade I	Grade II	Grade III	Total Observations
Observations	33	16	8	**57**
Percentages	58%	28%	14%	**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 Table 3.8.

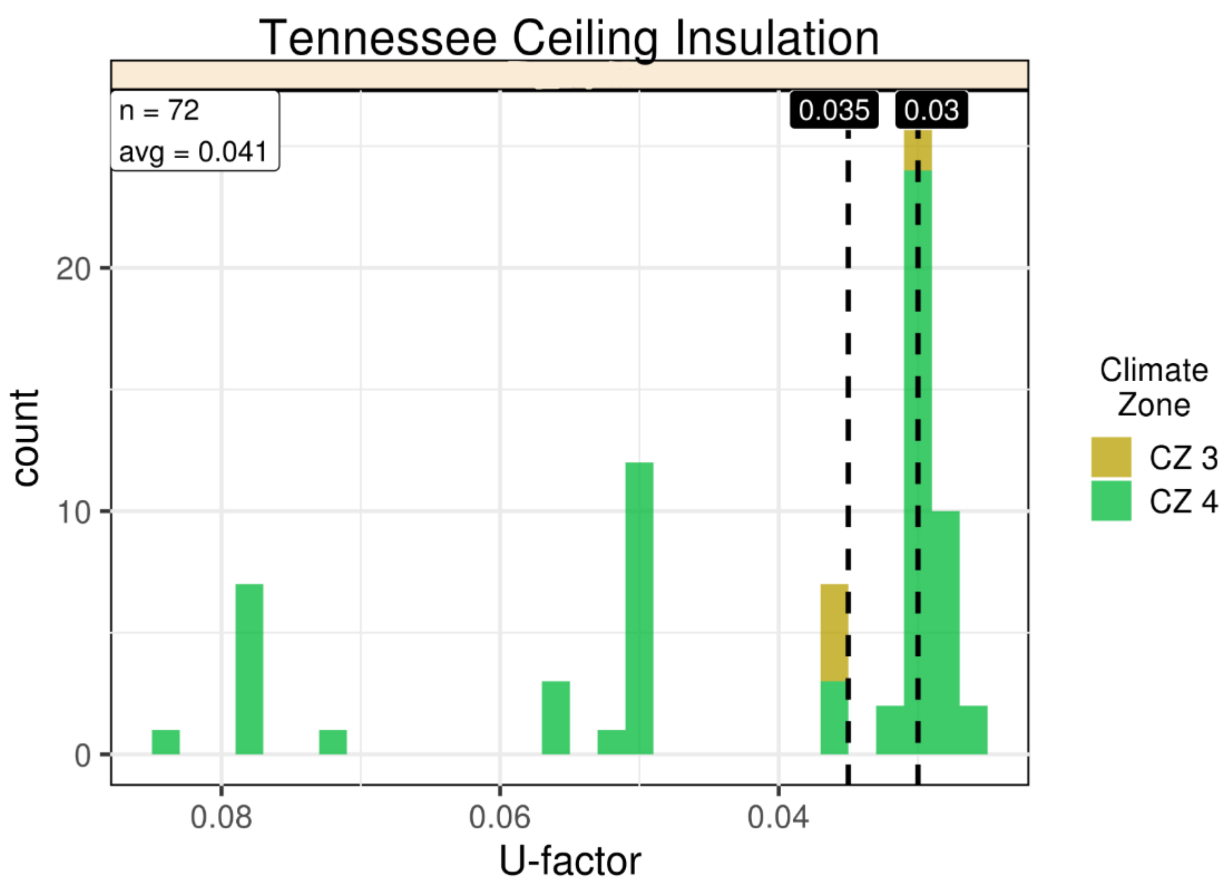

Figure 3.7. Ceiling U-Factors for Tennessee

Table 3.9. Tennessee Ceiling U-Factor

Climate Zone	CZ3	CZ4	Statewide
Number	6	66	72
Range	0.035 to 0.029	0.084 to 0.026	0.084 to 0.026
Average	0.033	0.041	0.041
Requirement	0.035	0.03	Varies by CZ
Compliance Rate	6 of 6 (100%)	36 of 66 (55%)	42 of 72 (58%)

- **Interpretations:**
  - The majority (83%) of the R-value observations meet or exceed the requirement.
  - However, a much smaller percentage (58%) of the U-factor values meet the U-factor requirement, indicating that IIQ is an issue.
  - In terms of IIQ, 33 of 57 (58%) observations were rated Grade I. These Grade I observations are the ones that comply with the U-factor requirement.
  - While cavity insulation appears to be achieved successfully (R-value), the overall assembly performance (U-factor) represents an opportunity for improvement in the state through future education, training and other compliance-support programs.

3.1.1.5 Lighting

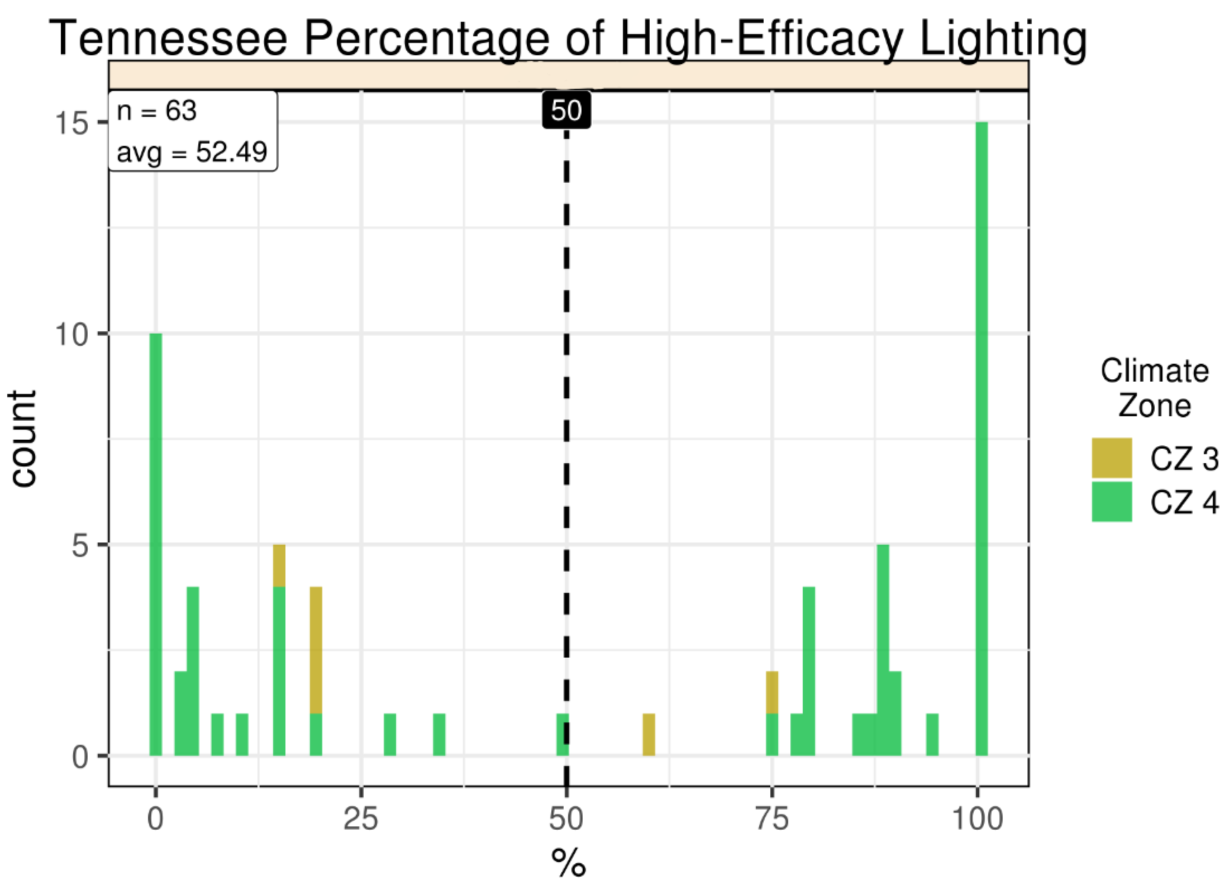

Figure 3.8. High-Efficacy Lighting Percentages for Tennessee

Table 3.10. Tennessee High-Efficacy Lighting Percentages

Climate Zone	CZ3	CZ4	Statewide
Number	6	57	63
Range	15 to 75	0 to 100	0 to 100
Average	35.00	54.33	52.49
Requirement	50.00	50.00	50.00
Compliance Rate	2 of 6 (33%)	32 of 57 (56%)	34 of 63 (54%)

- **Interpretations:**
  - Just over half (54%) of the field observations meet the prescriptive requirement. There are a significant quantity and wide range of non-compliant observations.
  - High-efficacy lighting represents an opportunity for improvement in the state through future education, training and other compliance-support programs.

3.1.1.6 Duct Tightness

For ducts, this report presents both raw duct leakage and adjusted duct leakage. Raw duct leakage is simply the values of duct leakage observed in the field. Adjusted duct leakage 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 leakage tests are not required if the ducts are entirely in conditioned space.

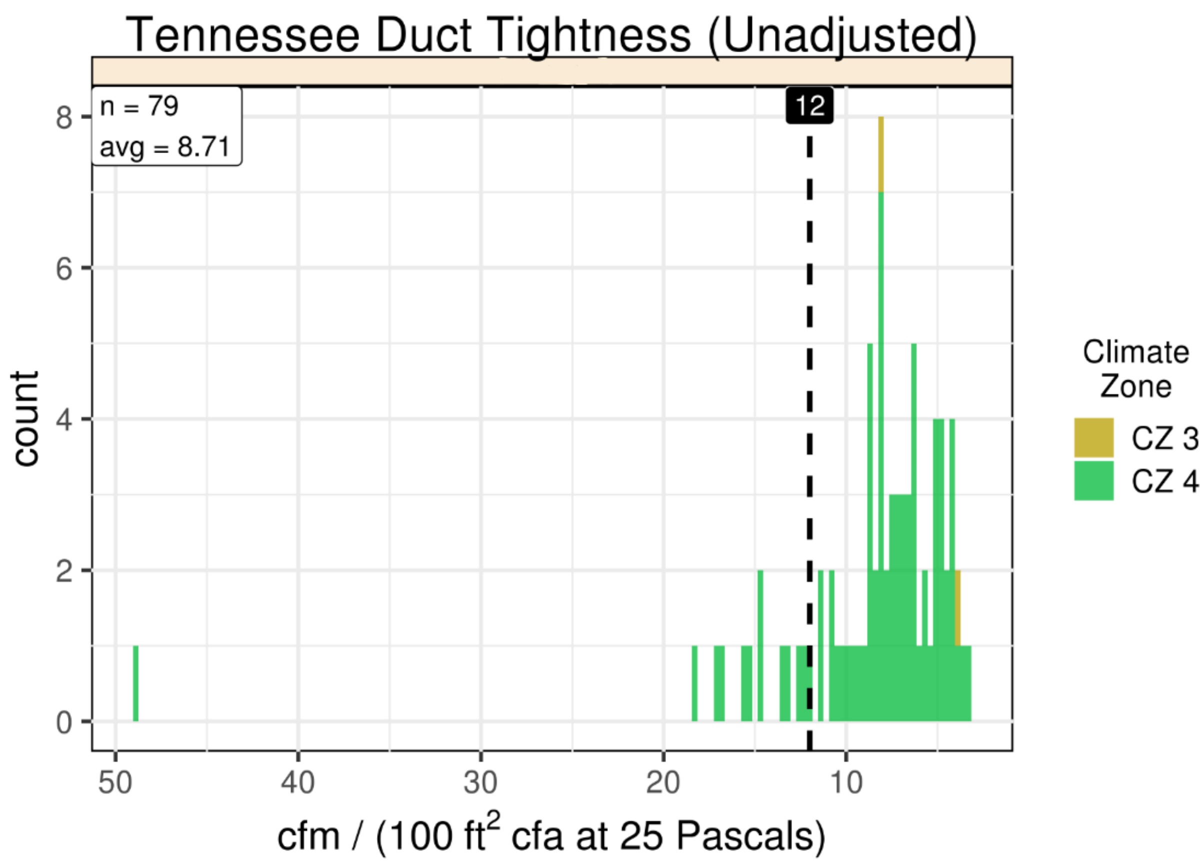

Figure 3.9. Duct Tightness (Unadjusted) Values for Tennessee

Table 3.11. Tennessee Duct Tightness Values (Unadjusted)

Climate Zone	CZ3	CZ4	Statewide
Number	2	77	79
Range	8.1 to 3.9	18.3 to 3.2	18.3 to 3.2
Average	6.00	8.77	8.71
Requirement	12.00	12.00	12.00
Compliance Rate	2 of 2 (100%)	65 of 77 (84%)	67 of 79 (85%)

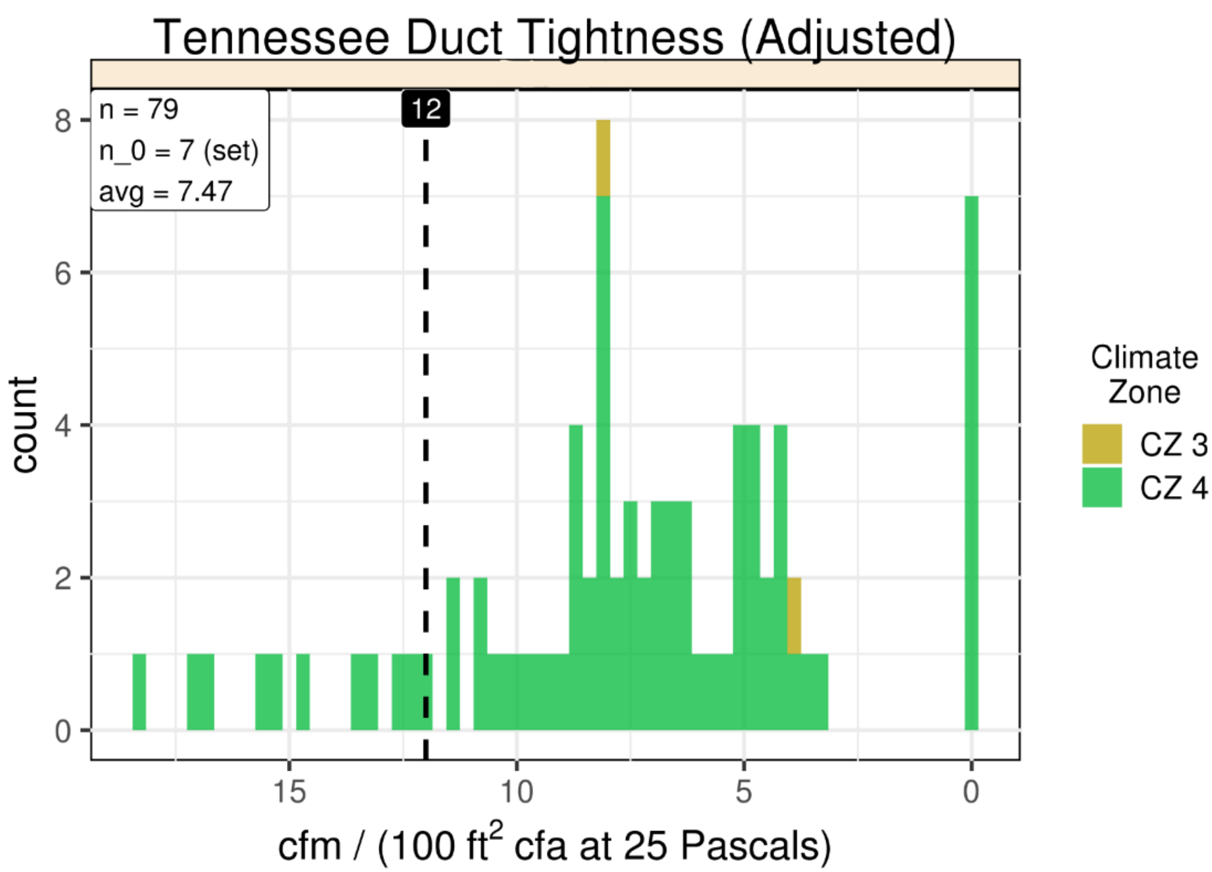

Figure 3.10. Adjusted Duct Tightness Values for Tennessee

Table 3.12. Tennessee Adjusted Duct Tightness

Climate Zone	CZ3	CZ4	Statewide
Number	2	77	79
Range	8.1 to 3.9	18.3 to 0.0	18.3 to 0.0
Average	6.00	7.51	7.47
Requirement	12.00	12.00	12.00
Compliance Rate	2 of 2 (100%)	67 of 77 (87%)	69 of 79 (84%)

- **Interpretations:**
  - Most (85%) of the unadjusted observations meet the requirement for duct leakage.
  - There is a single value of 49 that is an outlier in Figure 3.9. This home has ducts entirely in conditioned space, so the outlier disappears in Figure 3.10.
  - Based on adjusted duct leakage (accounting for ducts entirely in conditioned space), 84% met the prescriptive requirement. There were five homes with ducts entirely in conditioned space, including one home with two duct systems entirely in conditioned space, for a total of six duct systems.
  - Reductions in duct leakage represent an opportunity for improvement in the state through future education, training and other compliance-support programs.

3.1.1.7 Foundations

All four foundation types were observed in Tennessee, basements, crawlspaces, slabs and floors. However, the predominant foundation type observed was slabs. Basement walls include those observations where wall insulation is installed in a conditioned basement. Floors include those observations where floor insulation is installed, such as over vented crawlspaces and unconditioned basements. There was only a single basement wall observation, so no graph or table is included.

Two types of graphs are shown – R-value and U-factor. The R-value graph shows the insulation R-values observed. The U-factor graph indicates the U-factor of the assembly, including cavity insulation, continuous insulation, and framing, with consideration of insulation installation quality, as observed in the field. A summary table is also provided for the U-factor results (or R-value results in the case of slabs-on-grade.)

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

Basements

There was only a single basement wall observation, so no graph or table is included. That basement wall was in Climate Zone 4A and had cavity insulation of R-15 and IIQ of Grade III. The calculated U-factor is U-0.071 is above the code requirement of U-0.059, so this single wall did not meet the code requirement.

Slabs

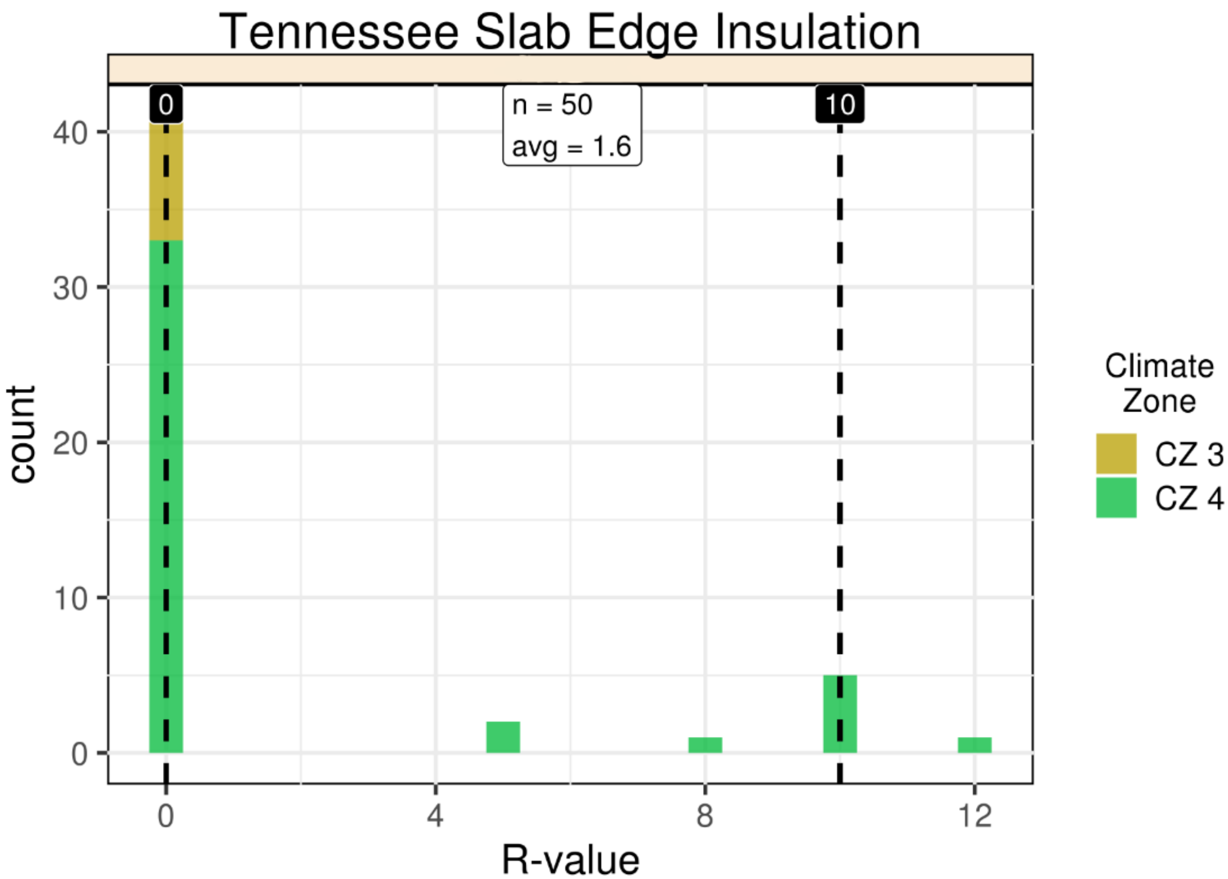

Figure 3.11. Slabs for Tennessee

Table 3.13. Tennessee Slabs

Climate Zone	CZ3	CZ4	Statewide
Number	8	42	50
Range	0.0 to 0.0	0.0 to 12.0	0.0 to 12.0
Average	0.0	1.9	1.6
Requirement	0.0	10	Varies by CZ
Compliance Rate	8 of 8 (100%)	6 of 42 (14%)	14 of 50 (28%)

- **Interpretations:**
  - Only 28% of the slab edge insulation observations met the requirements, including 16% which pass because they are in CZ 3 where there is no requirement.
  - No observations were collected to indicate the depth of the slab edge insulation in CZ 4.
  - Slab edge insulation represents an area for improvement and should be given increased attention in future training and enforcement.

Floors

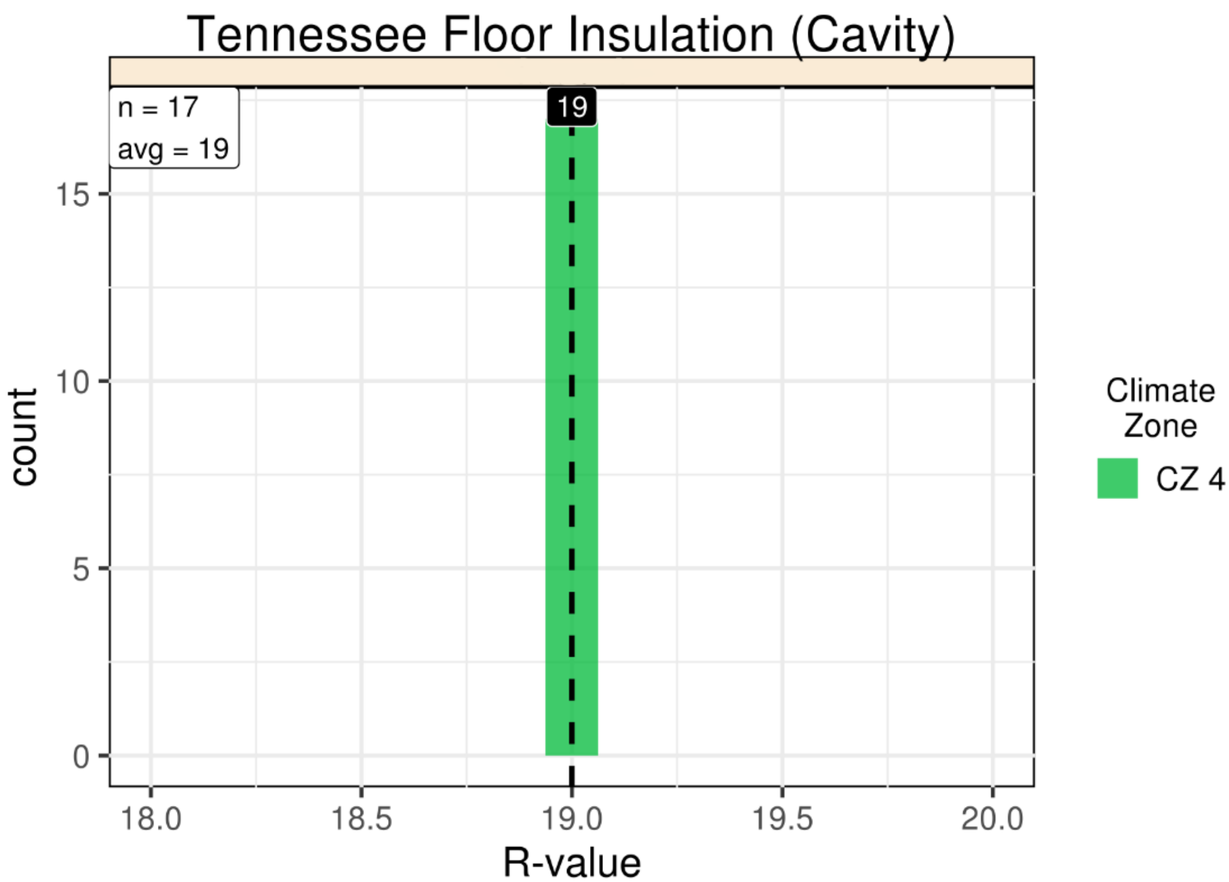

Figure 3.12. Tennessee Floor Cavity R-Values

Table 3.14 shows the number and percentage of IIQ observations by grade for floor insulation. 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 Table 3.15.

Table 3.14. Tennessee Floor IIQs

Floor	Grade I	Grade II	Grade III	Total Observations
Observations	0	6	11	**17**
Percentages	0%	35%	65%	**100%**

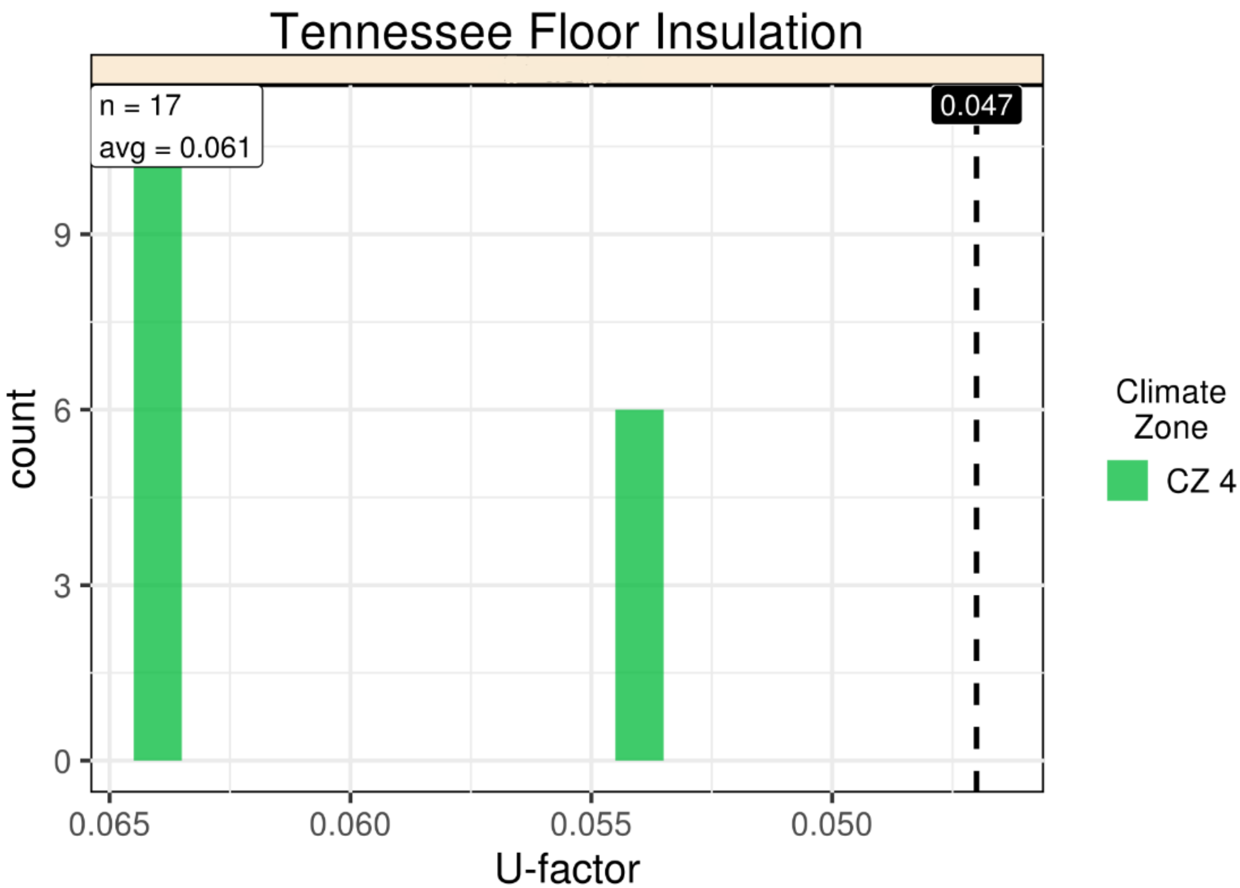

Figure 3.13. Floor U-Factors for Tennessee

Table 3.15. Tennessee Floor U-Factors

Climate Zone	**CZ3**	**CZ4**	**Statewide**
Number	0	17	17
Range	NA	0.064 to 0.054	0.064 to 0.054
Average	NA	0.061	0.061
Requirement	NA	0.047	0.047
Compliance Rate	NA	0%	0%

- **Interpretations:**
  - When considering R-values, all observations meet the prescriptive requirement, however, when considering U-factors, compliance is 0%. The implication is that IIQ for floors is a problem, and this is confirmed by Table 3.14, where there are no Grade I observations.
  - Note that the floor cavity R-value graph shows 1 distinct bar, while the floor U-factor graph shows 2 distinct bars. This is because all of the floor IIQ observations are Grade II or Grade III, which divides the R-19 results into two distinct U-factors, both of which fail.
  - Although the number of observations is low, floor insulation represents an opportunity for improvement in the state through future education, training and other compliance-support programs.

Crawlspaces

No cavity insulation R-value or continuous insulation R-value plots are shown for Tennessee crawlspace walls. Tennessee has 10 crawlspace wall observations as shown in the U-factor graph (Figure 3.14). Three of those observations are walls with only cavity insulation and seven are walls with only continuous insulation. All of these walls meet the respective insulation R-value requirements. The U-factor graph shows that the cavity only walls fail to meet the U-factor requirement because of Grade III IIQ.

Table 3.16 shows the number and percentage of IIQ observations by grade for crawlspace wall insulation. 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 Table 3.17.

Table 3.16. Tennessee Crawlspace Wall IIQs

Crawlspace	Grade I	Grade II	Grade III	Total Observations
Observations	4	0	3	**7**
Percentages	57%	0%	43%	**100%**

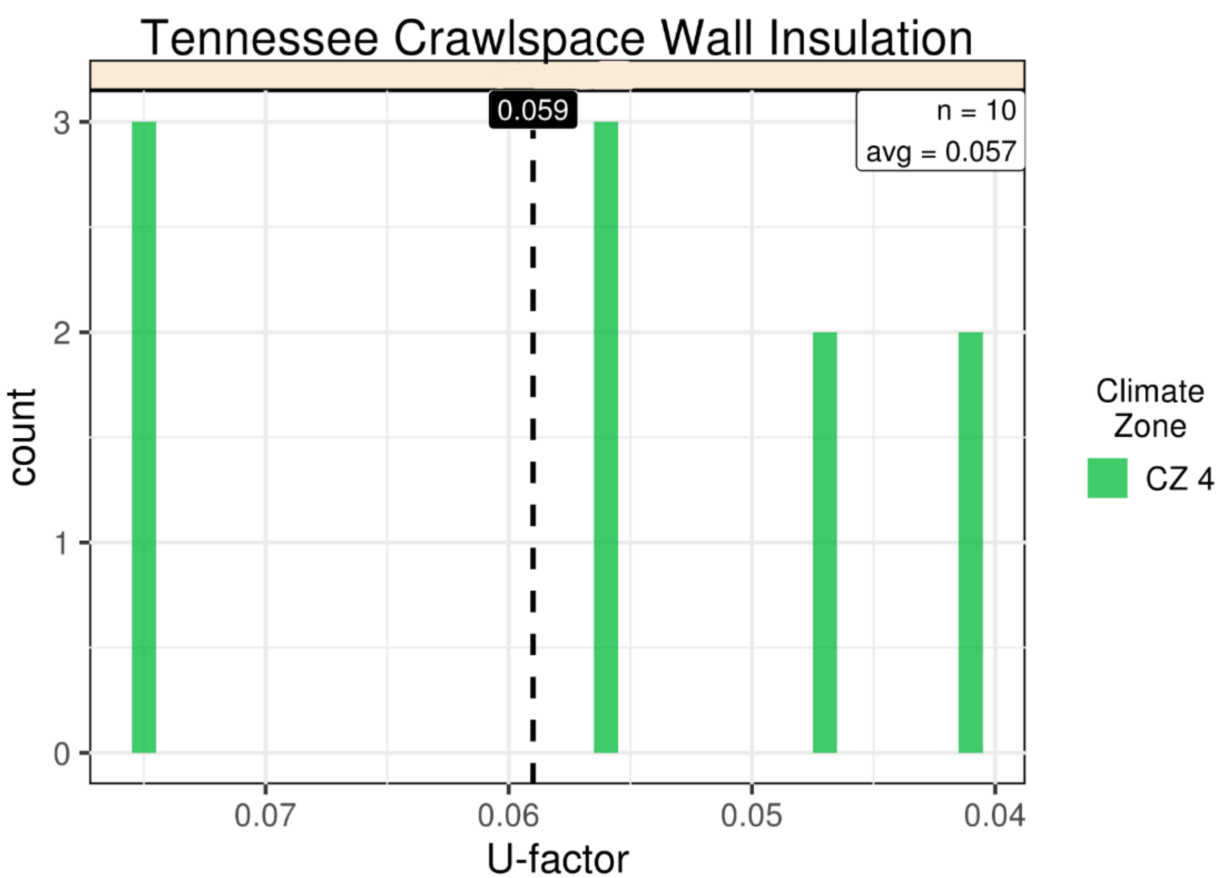

Figure 3.14. Crawlspace Wall U-Factors for Tennessee

Table 3.17. Tennessee Crawlspace Wall U-Factors

Climate Zone	CZ3	CZ4	Statewide
Number	0	10	10
Range	NA	0.075 to 0.041	0.075 to 0.041
Average	NA	0.057	0.057
Requirement	NA	0.059	0.059
Compliance Rate	NA	7 of 10,(70%)	7 of 10 (70%)

- **Interpretations:**
  - All crawlspace R-values for both cavity and continuous insulation observations meet or exceed the prescriptive requirement. However, all cavity insulation crawlspace walls fail to meet the U-factor requirements because of IIQ issues, with all three of these walls being Grade III.

3.1.2 Additional Data Items

The project team collected data on additional code requirements (beyond the key items) 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, in addition to the key items alone.

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. The full data set, including some additional data that did not have enough observations to be deemed meaningful, is also available on the DOE Building Energy Codes Program website.[3]

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

- Size: 2207 ft^2 (n=105) and 1.64 stories (n=126)

Table 3.18. Conditioned Floor Area (ft^2)

Conditioned Floor Area (ft^2)	< 1000	1000 to 1999	2000 to 2999	3000 to 3999	4000+
Percentage	1%	50%	29%	17%	4%

Table 3.19. Number of Stories

No. of Stories	1	1.5	2	3	4+
Percentage	37%	1%	60%	2%	0%

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

3.1.2.2 Envelope

- Foundations (n=130): Mix of slab-on-grade (59%), unvented crawlspace (22%), vented crawlspace (17%), and basements (2%)

3.1.2.3 Duct & Piping Systems

- Ducts were often not located within conditioned space (percentage of duct system):
  - Supply (n=69): 28%
  - Return (n=68): 29%
- Ducts located entirely in conditioned space:
  - Supply (n=69): 12% of systems
  - Return (n=68): 12% of systems

3.1.2.4 HVAC Equipment

- Heating (n=77): Split between electric heat pump (62%) and gas furnace (38%)
- Cooling (n=4): Split between central AC (50%) and heat pump (50%)

3.2 Energy Intensity

The statewide energy analysis results are shown in Figure 3.15, which compares the weighted average energy consumption of the observed data set to the weighted average consumption based on the state energy code. The observed data set (as gathered in the field) was compared against the same set of homes meeting prescriptive code requirements. In terms of overall energy consumption, homes in Tennessee appear to use less energy than would be expected relative to homes built to the current minimum state code requirements.

Analysis of the collected field data indicates an average regulated EUI (dashed line in Figure 3.15) of approximately 23.47 kBtu/ft^2-yr compared to 26.08 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements (black line in Figure 3.15). This suggests the EUI for a “typical” home in the state is about 10.0% better than the 2015 Tennessee Energy Conservation Code.

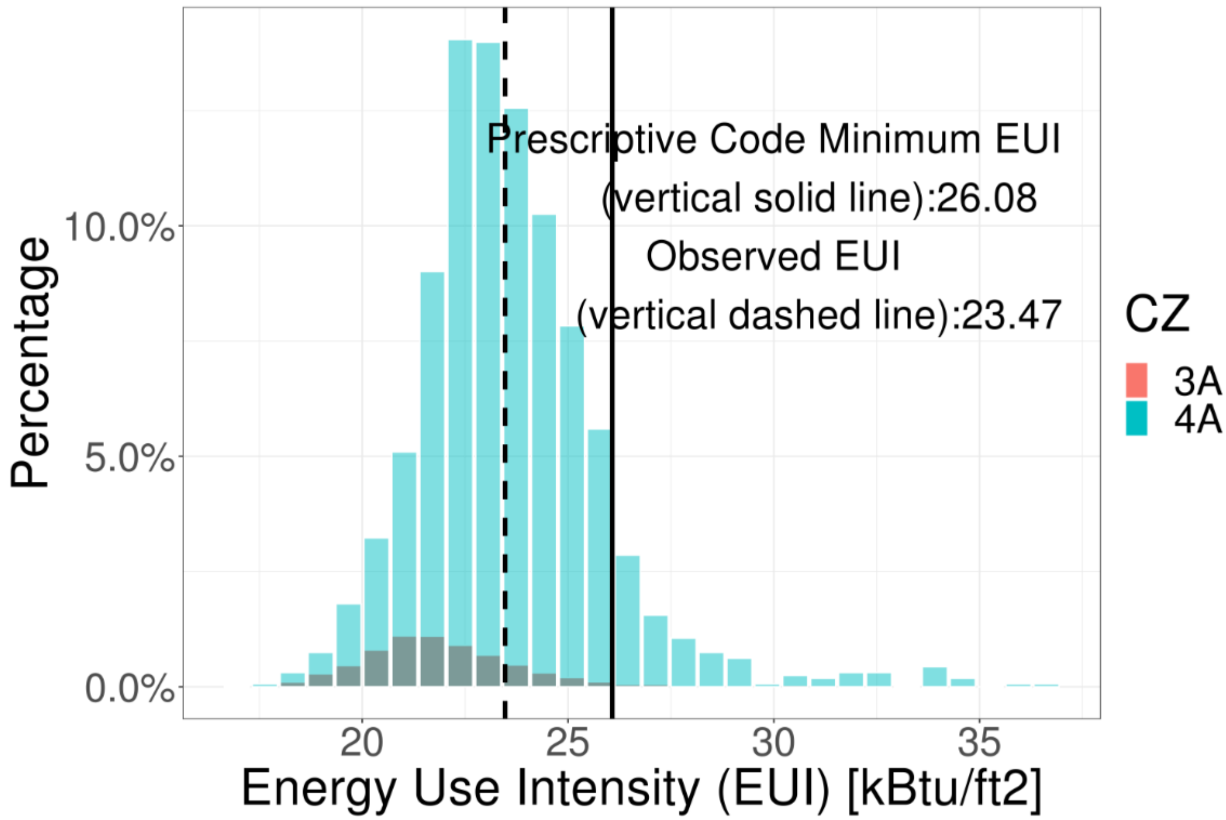

Figure 3.15. Statewide EUI Analysis

3.3 Savings Potential

Tennessee was one of the first states for which BECP decided to calculate measure level savings potential for all key items that had at least one observation that did not meet code, as opposed to previous state analyses where a 15% failure threshold was used. Shown below is a list of key items analyzed, followed by the percent of observations that met or exceeded the associated code requirement. Note that percentages are based on U-factors for any opaque assemblies, except for slab insulation, which is based on R-value. Any key item where the percentage was less than 100 is listed and was analyzed further to calculate the associated savings potential, including energy, cost and carbon savings.[4]

- Exterior Wall Insulation (16%),
- Ceiling Insulation (58%),
- Foundations
  - Heated Basement Wall Insulation (0%)
  - Floors over Unconditioned Space (unheated basement or vented crawlspace) (0%)
  - Walls of unvented crawlspaces (70%)
  - Slabs-on-grade (28%)

[4] Window U-factor is not included in the list because the compliance rate was 100%.

- Lighting (54%),
- Envelope Air Tightness (95%),
- Window SHGC (99%), and
- Duct Leakage (84%).

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

Estimated savings potential resulting from the analysis are shown below in order of highest to lowest total energy, cost and environmental impact savings (Table 3.20). As can be seen, there are significant savings opportunities, with the greatest total energy savings potential associated with these measures. In addition, Table 3.22 shows the total savings and environmental impact reductions that will accumulate over 5, 10, and 30 years of construction.

Table 3.20. Statewide Annual Measure-Level Savings Potential

Measure	Climate Zone	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)
Exterior Wall Insulation	3A	214	6	1,374	1,919	2,636	56,816	2,185
	4A	230	8	1,548	26,102	40,395	847,847	31,934
	Total	**229**	**8**	**1,536**	**28,021**	**43,032**	**904,664**	**34,119**
Ceiling Insulation	3A	106	3	649	1,919	1,245	27,536	1,080
	4A	156	5	989	26,102	25,823	561,331	21,730
	Total	**153**	**4**	**966**	**28,021**	**27,068**	**588,867**	**22,810**
High Efficacy Lighting*	3A	147	-1	432	1,919	829	29,799	1,499
	4A	145	-1	420	26,102	10,976	397,669	20,059
	Total	**145**	**-1**	**421**	**28,021**	**11,805**	**427,468**	**21,557**
Envelope Air Tightness	3A	54	2	403	1,919	774	15,439	557
	4A	59	2	452	26,102	11,787	231,596	8,243
	Total	**59**	**2**	**448**	**28,021**	**12,561**	**247,035**	**8,800**
Duct Leakage	3A	45	1	243	1,919	467	11,135	460
	4A	52	1	275	26,102	7,187	172,926	7,184
	Total	**51**	**1**	**273**	**28,021**	**7,653**	**184,062**	**7,644**
Foundation Insulation*	3A	-29	3	176	Varies	45	-310	-50
	4A	48	6	808	Varies	10,322	179,714	5,647
	Total	**-22**	**3**	**236**	**Varies**	**10,367**	**179,403**	**5,598**
Window SHGC	3A	0	0	0	1,919	0	0	0
	4A	5	0	44	26,102	1,160	21,407	717
	Total	**5**	**0**	**41**	**28,021**	**1,160**	**21,407**	**717**
Total	3A	538	14	3,277	1,919	5,997	140,415	5,731
	4A	696	22	4,536	26,102	107,649	2,412,490	95,514
	Total	**620**	**18**	**3,922**	**28,021**	**113,646**	**2,552,905**	**101,245**

* 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 3.21. Breakdown of Foundation Measure Level Savings Potential

Measure	Climate Zone	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)
Slab Insulation	3A	0	0	0	1,230	0	0	0
	4A	69	3	565	16,732	9,454	179,120	6,160
	Total	**0**	**0**	**0**	**17,962**	**9,454**	**179,120**	**6,160**
Unvented Crawlspace Wall Insulation	3A	4	0	37	246	9	162	5
	4A	5	0	42	3,346	141	2,503	81
	Total	**4**	**0**	**42**	**3,592**	**150**	**2,665**	**86**
Heated Basement Wall Insulation	3A	-8	1	56	25	1	-3	-1
	4A	-6	1	77	335	26	97	-10
	Total	**-6**	**1**	**75**	**359**	**27**	**94**	**-11**
Floor Over Vented Crawlspace	3A	-25	2	83	418	35	-469	-54
	4A	-20	2	123	5,689	701	-2,007	-583
	Total	**-20**	**2**	**119**	**6,107**	**736**	**-2,476**	**-637**
TOTAL	3A	-29	3	176	Varies	45	-310	-50
	4A	48	6	808	Varies	10,322	179,714	5,647
	Total	**-22**	**3**	**236**	**Varies**	**10,367**	**179,403**	**5,598**

Table 3.22. Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Potential

	Total Energy Savings Potential (MMBtu)			Total Energy Cost Savings Potential ($)			Total State Emissions Reduction Potential (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Exterior Wall Insulation	645,478	2,366,751	20,009,805	13,569,953	49,756,494	420,668,544	511,783	1,876,537	15,865,267
Ceiling Insulation	406,015	1,488,721	12,586,458	8,833,008	32,387,695	273,823,242	342,145	1,254,533	10,606,506
High Efficacy Lighting	177,074	649,270	5,489,285	6,412,015	23,510,722	198,772,471	323,360	1,185,654	10,024,161
Envelope Air Tightness	188,415	690,856	5,840,869	3,705,528	13,586,935	114,871,358	132,004	484,016	4,092,133
Duct Leakage	114,802	420,941	3,558,867	2,760,925	10,123,392	85,588,680	114,660	420,419	3,554,450
Foundation Insulation	155,505	570,186	4,820,667	2,691,049	9,867,178	83,422,506	83,963	307,864	2,602,854
Window SHGC	17,397	63,790	539,312	321,103	1,177,378	9,954,193	10,757	39,442	333,462
Total	1,704,686	6,250,515	52,845,263	38,293,580	140,409,795	1,187,100,994	1,518,672	5,568,464	47,078,834

4.0 Conclusions

The Tennessee field study provides an enhanced understanding of statewide code implementation, and suggests that additional savings are available through increased compliance with the state energy code. From a statewide perspective, the average home in Tennessee uses about 10% less energy than a home exactly meeting the state energy code. However, significant savings potential remains through increased compliance with targeted measures. Potential statewide annual energy savings are 113,646 MMBtu, which equates to over $2.55 million in cost savings, and emission reductions of over 101,000 MT CO2e. Over a 30-year period, these impacts grow to nearly 53 million MMBtu, nearly $1.2 billion, and over 47 million CO2e in avoided environmental impacts.

Several key measures directly contribute to these savings, and should be targeted through future education, training and outreach activities. In particular, there are significant savings opportunities for wall and ceiling insulation through improved IIQ. The savings associated with each are shown in Table 4.1.

Table 4.1. Annual Statewide Savings Potential

Measure	**Total Energy Savings Potential** (MMBtu)	**Total Energy Cost Savings Potential** ($)	**Total State Emissions Reduction Potential** (MT CO2e)
Exterior Wall Insulation	43,032	904,664	34,119
Ceiling Insulation	27,068	588,867	22,810
Lighting	11,805	427,468	21,557
Envelope Air Tightness	12,561	247,035	8,800
Duct Leakage	7,653	184,062	7,644
Foundation Insulation	10,367	179,403	5,598
Window SHGC	1,160	21,407	717
TOTAL	**113,646 MMBtu**	**$2,552,905**	**101,245 MT CO2e**

5.0 References

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Appendix A

Stakeholder Participation

Appendix A

Stakeholder Participation

The Tennessee Project Team held a stakeholder kick-off meeting on March 30, 2017 with the Tennessee Department of Environment & Conservation, Tennessee Department of Commence & Insurance, and other stakeholders. The team also met with a range of other stakeholders in Tennessee on an individual basis in order to understand the shortcomings in code enforcement, including the Tennessee Valley Authority (TVA), local power corporations (LPCs), city staff in Nashville, Knoxville, and Memphis, HERS raters, and local Home Builders Associations (HBAs). In addition, the project team connected with additional stakeholders during presentations at the Home Performance Annual Conference in Nashville and the East Tennessee Code Officials Conference in Sevierville.

Appendix B

State Sampling Plan

Appendix B

State Sampling Plan

B.1 State Sampling Plan

Table B.1. State Sampling Plan

Location	Sample	Actual
Nashville-Davidson, Davidson County	14	14
Knox County Unincorporated Area, Knox County	1	1
Murfreesboro, Rutherford County	3	3
Franklin, Williamson County	2	2
Rutherford County Unincorporated Area, Rutherford County	1	1
Shelby County Unincorporated Area, Shelby County	1	1
Spring Hill town, Maury County	2	2
Hamilton County Unincorporated Area, Hamilton County	1	1
Chattanooga, Hamilton County	2	2+2 (from Montgomery County Unincorporated Area) = 4
Gallatin, Sumner County	1	1
Williamson County Unincorporated Area, Williamson County	2	2
Montgomery County Unincorporated Area, Montgomery County	2	0 (Additional homes visited in Chattanooga, Hamilton County)
Wilson County Unincorporated Area, Wilson County	3	3+1 (from Smith County Unincorporated Area) = 4
Lebanon, Wilson County	1	1
Smyrna town, Rutherford County	2	2
Sevier County Unincorporated Area, Sevier County	1	1
Knoxville, Knox County	2	2
Thompsons Station town, Williamson County	1	1
Hendersonville, Sumner County	1	1
Bartlett, Shelby County	2	2
Bradley County Unincorporated Area, Bradley County	2	2+1 (from Bedford County Unincorporated Area) = 3
Loudon County Unincorporated Area, Loudon County	1	1+1 from Greene County Unincorporated Area = 2
Johnson City, Washington County	1	1+ 1 (from Washington County Unincorporated Area) = 2
Maury County Unincorporated Area, Maury County	3	3+1 (from Macon County Unincorporated Area) = 4
Collierville town, Shelby County	1	1
Washington County Unincorporated Area, Washington County	1	0 (Additional homes visited in Johnson City, Washington County)
Putnam County Unincorporated Area, Putnam County	1	1 – Replaced with Sumner County Unincorporated Area

Location	Sample	Actual
Maryville, Blount County	2	2
Bedford County Unincorporated Area, Bedford County	1	0 (Additional homes visited in Bradley County Unincorporated Area)
Greene County Unincorporated Area, Greene County	1	0 (Additional homes visited in Loudon County Unincorporated Area)
Fayette County Unincorporated Area, Fayette County	2	2
Macon County Unincorporated Area, Macon County	1	0 (Additional homes visited in Maury County Unincorporated Area)
Smith County Unincorporated Area, Smith County	1	0 (Additional homes visited in Wilson County Unincorporated Area)
Total	**63**	**63**

B.2 Substitutions

In the Tennessee study, the project team had to substitute 8 samples in total due to samples not being available in the original jurisdiction. The substitute counties were selected to best match the social demographics of the original county. The following substitutions were made:

- Original: Montgomery County Unincorporated Area, Montgomery County. Substitution: Chattanooga, Hamilton County.
- Original: Washington County Unincorporated Area, Washington County. Substitution: Johnson City, Washington County.
- Original: Putnam County Unincorporated Area, Putnam County. Substitution: Sumner County Unincorporated Area, Sumner County.
- Original: Bedford County Unincorporated Area, Bedford County. Substitution: Bradley County Unincorporated Area, Bradley County.
- Original: Greene County Unincorporated Area, Greene County. Substitution: Loudon County Unincorporated Area, Loudon County.
- Original: Macon County Unincorporated Area, Macon County. Substitution: Maury County Unincorporated Area, Maury County.
- Original: Smith County Unincorporated Area, Smith County. Substitute: Wilson County Unincorporated Area, Wilson County.

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 Tennessee 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=105): 2207 ft^2
- Number of Stories (n=126): 1.64

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	1%	50%	29%	17%	4%

Table C.2. Number of Stories

No. of Stories	1	1.5	2	3	4+
Percentage	37%	1%	60%	2%	0%

C.1.1.2 Wall Profile

- Framing Type (n=6):
  - *All* were framed construction (100%) (There were actually at least 63 framed walls as the other questions in this section suggest, but only 6 walls were specifically listed as framed walls.)
- Framing Depth (n=5):

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

– 4” (80%)
– 6” (20%)

C.1.1.3 Foundation Profile

- Foundation Type (n=130):
  – Slab on Grade (59%)
  – Unvented Crawlspace (22%)
  – Vented Crawlspace (17%)
  – Heated Basement (2%)

C.1.2 Envelope

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

C.1.2.1 Insulation Labels

- Was insulation labeled (n=4)?
  – Yes (100%)
  – No (0%)

C.1.3 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.1.3.1 System Profile

- Duct Location in Conditioned Space (percentage):
  – *Supply* (n=69): 28% (8 systems located entirely within conditioned space)
  – *Return* (n=68): 29% (8 systems located entirely within conditioned space)

C.1.4 HVAC Equipment

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

C.1.4.1 Heating

- Fuel Source (n=57):
  – Gas (37%)
  – Electricity (63%)
- System Type (n=77):
  – Furnace (38%)

  - Heat Pump (62%)

C.1.4.2 Cooling

- System Type (n=4):
  - Central AC (50%)
  - Heat Pump (50%)

C.1.4.3 Water Heating

- Fuel Source (n=6):
  - Gas (83%)
  - Electric (17%)
- System Type (n=6):
  - Storage (17%)
  - Tankless (83%)

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