PNNL-30857

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Alabama Residential Energy Code Field Study: Final Report

September 2022

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

U.S. DEPARTMENT OF ENERGY

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

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights**. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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-30857

Alabama Residential Energy Code Field Study: Final Report

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

September 2022

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

Background

The baseline field study (Phase I) was initiated in March 2014 and continued through May 2014. During this period, research teams visited 134 homes during various stages of construction, resulting in a substantial data set based on observations made directly in the field. Analysis of the Phase I data led to a better understanding of the energy features typically present in Alabama homes, and indicated over $1,300,000 in potential annual savings to homeowners in the state that could result from increased code compliance (Table ES.2).

Starting in July 2016 and continuing through September 2017, members of the Alabama field study team conducted targeted education and training activities (Phase II). Those activities included development of a toolkit of resources targeted to home builders, designers and building code officials and in-person trainings. More information on the specific education and training activities employed in the state is included in Section 2.5. Following the baseline study and the education and training phases, the research team conducted the post-study (Phase III), visiting an additional 126 homes across the state between December 2017 and March 2018. The results of this effort are presented Table ES.1 and discussed further in Section 3.0.

Methodology

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

[1] See Section 2.1.

Following each data collection phase, PNNL conducted three stages of analysis on the resulting data set (Figure ES.1). The first stage identified compliance trends within the state based on the distributions observed in the field for each key item. The second modeled energy consumption of the homes observed in the field relative to what would be expected if sampled homes just met minimum code requirements. The third stage then calculated results based on three metrics emphasized by states as of interest relative to tracking code implementation status—potential energy savings, consumer cost savings, and environmental impacts associated with increased code compliance. Together, these findings provide valuable insight on challenges facing energy code implementation and enforcement.

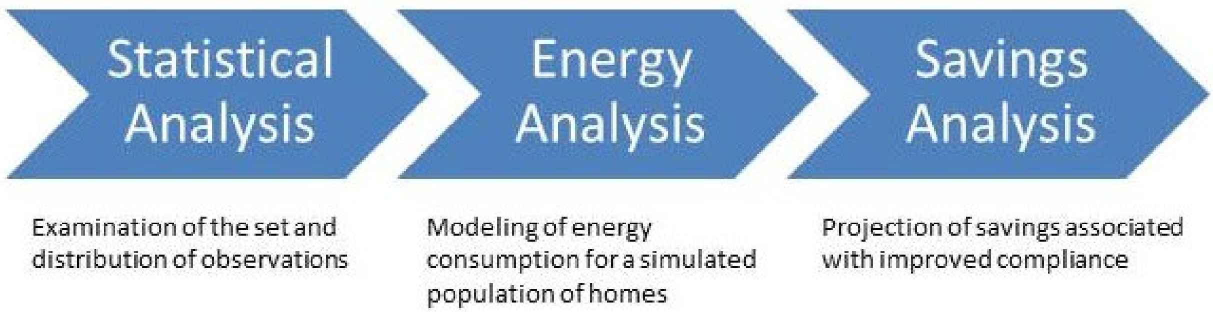

Figure ES.1. Stages of Analysis Applied in the Study

At the time of the initiation of Phase I of the study, the state energy code was based on the 2009 International Energy Conservation Code (IECC). Following data collection in Phase I, the state adopted an updated energy code, known as the 2015 Alabama Residential Energy Code.[2] All data in Phase I of this study was collected from homes permitted under the 2009 code; potential savings, however, were calculated against the 2015 code, as that is the code that homes would need to comply with in the future, and that was the focus of training in the state. Data collected in Phase III of the study was from homes permitted under the 2015 code. All of the results noted in this report are based on the 2015 Alabama code.

Success for the study is characterized by the following between Phase I and Phase III: 1) a measurable decrease in estimated statewide energy use [a change in energy use intensity (EUI) of at least 1.25 kBtu/ft^2] and 2) a reduction in measure-level savings potential. To estimate average statewide energy consumption, field data was analyzed to calculate average statewide energy use as characterized by EUI. Field observations from Phase I and Phase III were analyzed independently and compared to a scenario based on the state energy code's minimum prescriptive requirements. The Phase III results were then compared to the Phase I results to determine whether a measurable change could be detected.

Results

As shown in Table ES.1, the Phase I analysis indicated homes used about 7.6 percent more energy than would be expected relative to homes built to the minimum prescriptive requirements of the current state code. This percentage improved to 3.4 percent in Phase III, representing a change in EUI of approximately 3.9 percent (0.77 kBtu/ft^2) between Phases I and III. However, the change detected in statewide energy use between Phase I and Phase III did not meet the study's established threshold of a statistically significant improvement (1.25 kBtu/ft^2).

---

[2] The 2015 Alabama Residential Energy Code is based on the 2015 IECC with state amendments and is available at https://adeca.alabama.gov/Divisions/energy/energycodes/Energy%20Codes/Alabama%20Energy%20and%20Residential%20Code.pdf

Table ES.1. Average Modeled Energy Use Intensity in Alabama (kBtu/ft2-yr)

Prescriptive EUI[3]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
18.41	19.81	+7.6%	19.04	+3.4%	-3.9%

Next, the field data was assessed from the perspective of individual energy efficiency measures, or the key items with the greatest potential for savings in the state, as presented in Table ES.2. These figures represent the potential annual savings associated with each observable measure compared to a counterfactual scenario where all observations meet the prescriptive code requirement. The statistical trends were then extrapolated based on projected new construction across the state. These items, as identified in the Phase I baseline field study, were targeted as a focal point for Phase II education and training activities, and then reassessed following the Phase III study to examine whether a measurable change was detected. Improvement is achieved through a *reduction* in measure-level savings potential between Phases I and III.

Table ES.2. Estimated Annual Statewide Cost Savings Potential

	Total Energy Cost Savings Potential ($)		$ Change	% Change
Measure	**Phase I**	**Phase III**	**Phase III vs. I**	**Phase III vs. I**
Duct Tightness	395,063	323,238	-71,824	-18.2
Lighting	385,451	290,649	-94,802	-24.6
Envelope Air Tightness	263,089	185,084	-78,005	-29.6
Exterior Wall Insulation	201,105	175,080	-26,025	-12.9
Window SHGC	54,674	4,534	-50,140	-92%
TOTAL	**$1,299,382**	**$978,585**	**-$320,797**	**-25%**

Overall, there was a reduction in savings potential between Phase I and Phase III. This is an improvement of over 25 percent and over $320,000 in annual cost savings achieved by Phase II targeted education and training activities. Despite the positive impact of the project, a savings potential of nearly $1 million still remains that can be further reduced through targeted education and training.

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

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

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

Acknowledgements

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

- Ryan Meres, *Institute for Market Transformation (IMT)*
- Kim Cheslak, *IMT*
- *Kelly Crandall, IMT*
- Heather Goggin, *Alabama Department of Economic and Community Affairs (ADECA)*
- Jeff Domanski, *Institute for Building Technology and Safety*
- Jerry Adams, *Calhoun Community College*
- Cadmus Group *(Cadmus, formerly Britt/Makela Group)*

IMT

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

ADECA

The Alabama Department of Economic and Community Affairs was created by the Legislature as an arm of the Governor's Office in 1983. The Legislature established ADECA to streamline the management of a number of programs administered by the state. ADECA is responsible for administering a broad range of state and federal programs that contribute to the department's mission — Building Better Alabama Communities. Find additional information on ADECA at http://adeca.alabama.gov/Pages/default.aspx.

IBTS

The Institute for Building Technology & Safety is a 501(c)(3) nonprofit organization established to provide unbiased professional building code compliance services directly to, or on behalf of, government agencies at all levels. These services include inspections, plan reviews, building department services, education and training, staff augmentation, policy and procedure development, cost evaluation, energy ratings, and auditing. More information is available at http://www.ibts.org/.

Calhoun Community College

Calhoun Community College is a technical college located in Decatur, AL, offering 49 associate degree options and 52 career/certificate programs. The Alabama Center for Excellence in Clean Energy

Technology at Calhoun Community College offers students and industry professionals training and education in the latest renewable energy and energy efficiency technologies and practices.

Cadmus

The Cadmus Group, Inc. was founded in 1983 in Watertown, MA. They provide services in the areas of energy, environment, high performance building, sustainability, public health, and strategic communications. See more information on Cadmus at https://www.cadmusgroup.com/.

Acronyms and Abbreviations

AC	air conditioning
ACH	air changes per hour
ADECA	Alabama Department of Economic and Community Affairs
AERC	Alabama Energy and Residential Codes Board
AL	Alabama
AFUE	annual fuel utilization efficiency
AHU	air handling unit
Btu	British thermal unit
cfm	cubic feet per minute
COAA	Code Officials Association of Alabama
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
HBAA	Home Builders Association of Alabama
HSPF	heating season performance factor
IBTS	Institute for Building Technology and Safety
ICC	International Code Council
IECC	International Energy Conservation Code
IMT	Institute for Market Transformation
kBtu	thousand British thermal units
MMBtu	million British thermal units
MT	metric ton
NA	not applicable
PNNL	Pacific Northwest National Laboratory
SHGC	solar heat gain coefficient

Contents

Figures

Tables

1.0 Introduction

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

The baseline field study (Phase I) was initiated in March 2014 and continued through May 2014. During this period, research teams visited 134 homes across the state during various stages of construction, resulting in a substantial data set based on observations made directly in the field. Analysis of the Phase I data led to a better understanding of the energy features typically present in Alabama homes, and indicated nearly $1,300,000 in potential annual savings to homeowners in the state that could result from increased code compliance.

Starting in July 2016 and continuing through September 2017, members of the Alabama field study team conducted targeted education and training activities (Phase II). Those activities included development of a toolkit of resources targeted to home builders, designers and building code officials and in-person trainings. More information on the specific education and training activities employed in the state is included in Section 2.5. Following the baseline study and the education and training phases, the research team conducted the post-study (Phase III), visiting an additional 126 homes across the state between December 2017 and March 2018. The results of this effort are presented in Section 3.0. At the time of the study, the state energy code was based on the 2009 International Energy Conservation Code (IECC) with some amendments. Following data collection, the state proceeded in adopting an updated energy code, known as the 2015 Alabama Residential Energy Code.[1] All data in this study was collected from homes permitted under the 2009 code; however, results were analyzed against the 2015 code. The study methodology, data analysis and resulting findings are presented throughout this report.

1.1 Background

The data collected and analyzed for this report was in response to the U.S. Department of Energy (DOE) Funding Opportunity Announcement (FOA)[2] with the goal of determining whether an investment in education, training, and outreach programs can produce a significant, measurable change in single-family residential building code energy use. Participating states:

---

[1] The 2015 Alabama Residential Energy Code is based on the 2015 IECC with state amendments and is available at http://adeca.alabama.gov/Divisions/energy/energycodes/Energy%20Codes/2015%20Alabama%20Residential%20Energy%20Code%20(effective%2010-1-16).pdf

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

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

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

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

Energy codes for residential buildings have advanced significantly in recent years, with today's model codes approximately 30% more efficient than codes adopted by the majority of U.S. states. [3,4] Hence, the importance of ensuring code-intended energy savings, so that homeowners realize the benefits of improved codes—something which happens only through high levels of compliance. More information on the original FOA and overall goals of the study is available on the DOE Building Energy Codes Program website.[5]

1.2 Project Team

The Alabama project was led by the Institute for Market Transformation (IMT), with support from the Alabama Department of Economic and Community Affairs (ADECA), and field data collected by Cadmus. The Institute for Building Technology and Safety and Calhoun Community College provided, education and training efforts. 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

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

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

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

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

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

2.0 Methodology

2.1 Overview

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

Highlights of the methodology:

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

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

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

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

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

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

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

2.2 State Study

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

2.2.1 Sampling

PNNL developed statewide sampling plans statistically representative of recent construction activity within the state. For Alabama, sampling plans were based on the average of the 19 most recent months of Census Bureau permit data[4]. The sampling plan specified the number of key item observations required in each selected county (totaling 63 of each key item across the entire state).

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

2.2.2 Data Collection

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

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 (the 2009 IECC). The final 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 eight key items), as well as additional items required under the

---

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

[4] Available at http://censtats.census.gov/ (select the "Building Permits" data)

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

prescribed methodology. For example, the field teams were required to conduct a blower door test and duct tightness test on every home where such tests could be conducted, using RESNET[6] protocols.

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

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

2.2.2.2 Data Management and Availability

Once each data collection effort was complete, the project team conducted a thorough quality assurance review. This included an independent check of raw data compared to the information provided to PNNL for analysis, and helped to ensure completeness, accuracy and consistency across the inputs. Prior to submitting the data to PNNL, the team also removed all personally identifiable information, such as project site locations and contact information. The final dataset for each Phase is available in spreadsheet format on the DOE Building Energy Codes Program website.[7]

2.3 Data Analysis

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

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

The first stage identified compliance trends within the state based on what was observed in the field for each key item. The second modeled energy consumption (of the homes observed in the field) relative to what would be expected if sampled homes just met minimum code requirements. The third stage then calculated potential savings based on several metrics of interest to states and utilities—energy savings, consumer cost savings, and avoided carbon emissions associated with increased code compliance. This combination of methods and metrics provides valuable insight on challenges facing energy code

[6] See https://www.resnet.us/wp-content/RESNET-Mortgage-Industry-National-HERS-Standards_3-8-17.pdf.
[7] Available at https://www.energycodes.gov/residential-energy-code-field-studies.

implementation in the field, and are intended to inform future energy code education, training and outreach activities.

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

2.3.1 Statistical Analysis

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

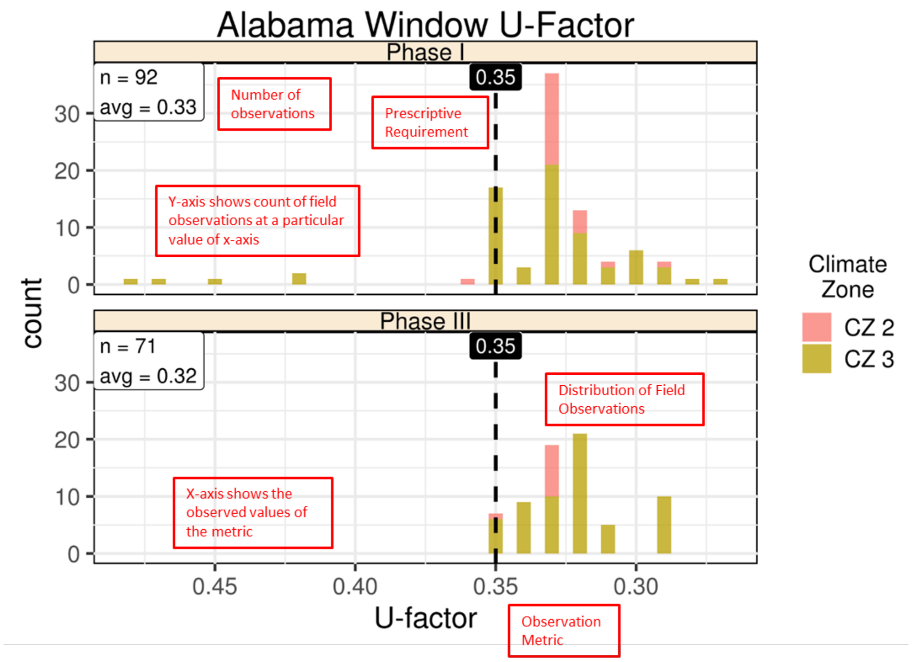

Figure 2.1. Sample Graph

Each graph is set up in a similar fashion, identifying the *state*, *climate zone*, and specific item being analyzed. The total *sample size* (n) is displayed in the top left or right corner of the graph, along with the distribution *average*. The *metric* associated with the item is measured along the horizontal axis (e.g., window U-factor is measured in Btu/ft2-hr-F), and a *count* of the number of observations is measured along the vertical axis. A vertical line is imposed on the graph representing the applicable code requirement (e.g., the prescriptive requirement in CZ2/3 is 0.35)—values to the right-hand side of this line represent observations which are *better than code*. Values to the left-hand side represent areas for improvement.

2.3.2 Energy Analysis

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

Energy simulation was then conducted using the EnergyPlus™ software.[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 stage, each of the key items was examined individually to determine which had a significant number of observed values that did not meet the associated code requirement[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).[11] The worse-than-code observations for the key item under consideration are used to create a second set of models (*as built*) that can be compared to the baseline (*full compliance*) models. All other components were maintained at the corresponding prescriptive code value, allowing for the savings potential associated with a key item to be evaluated in isolation.

All variations of observed heating systems and foundation types were included, and annual electric, gas and total EUIs were extracted for each building. To calculate savings, the differences in energy use calculated for each case were weighted by the corresponding frequency of each observation to arrive at an average energy savings potential. Potential energy savings were further weighted using construction starts to obtain the average statewide energy savings potential. State-specific construction volumes and

---

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

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

[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. However, if a measure met the 15% threshold in Phase I but not in Phase III, it was still included in the measure-level savings for Phase III regardless of the worse-than-code percentage so as not to potentially overstate savings by ignoring the reduced, but not necessarily zero, measure-level savings in Phase III.

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

fuel prices were used to calculate the maximum energy savings potential for the state in terms of *energy* (MMBtu), *energy cost* ($), and *avoided carbon emissions* (MT CO2e).

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

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

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

Under ideal circumstances, project teams would identify outliers at the time of data collection during field visits, and employ procedures to flag and evaluate atypical conditions, data points or observations. During the course of the data QA/QC process, remaining outliers were discussed with the project teams and, where applicable and appropriate, data were modified prior to analysis. Given that this was a research study, and in many cases valid extremes do exist in the field, it was decided to retain all other data outliers in the analysis. This allows a given team or state to understand the presence of, and related impacts, of valid outliers in their data set. The impact of this decision is that there may be some "extreme" data points that appear in the key item plots and impact the measure level savings and EUI results, which have been deliberately retained in the data set. In addition, the field methodology and related tools (e.g., data collection forms) were updated to help guide future data collection teams in proactively identifying potential outliers and to the greatest extent possible verifying (or mitigating) their impacts in the field. Where outliers occur for specific key items, these outliers will be noted and discussed.

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

2.4.4 Site Access

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

2.4.5 Analysis Methods

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

2.4.6 Presence of Tradeoffs

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

2.5 Phase II Targeted Education and Training

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

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

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

For Alabama, specific Phase II activities included[12]:

- Resource toolkit: Development of a toolkit of resources to help builders, designers, and code officials. Resources for builders and designers focused on training and educational materials to understand key areas of construction that are critical to achieving code compliance and energy savings. The resources included two particular focus areas, lighting and envelope tightness. Resources for code officials provide targeted areas of high non-compliance to be diligently checked.
  - An infographic on high-efficacy lighting that depicts the energy efficiency benefits, lower maintenance and better lighting quality of high-efficacy lighting was developed.
  - The infographic was used to develop a brochure highlighting the benefits of high-efficacy lighting that builders could provide to market their homes.
- In-person and online trainings: More in-depth trainings were designed for local plans examiners, inspectors, and builders to dig deeper into the major code changes and highlight specific areas that need attention. Twenty-three in-person and online trainings were completed between August 2016 and November 2017.
  - A one-hour training for builders covering a quick review of field study results and more in-depth information about how to comply with the key items was developed.
  - A training presentation on duct and envelope tightness, including a presentation of the field study results and the new code requirements was developed and was followed by hands-on demonstrations of envelope and duct sealing.
  - A training targeted to local plan reviewers and inspectors was created with the intention of developing local "energy code specialists" within local building departments across the state.

[12] See https://www.imt.org/how-we-drive-demand/building-energy-codes/alabama-residential-energy-code-field-study/ for more information.

2.6 Phase III Field Study and Analysis

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

1. Annual number of permits estimated for the state
2. Split of permits between climate zones in multi-climate zone states
3. Distribution of heating system types in the state
4. Distribution of foundation types in the state
5. Number of observations of key items per climate zone in multi-climate zone states used in the Monte Carlo simulations
6. For states in which the baseline energy code changed and for which PNNL compared the observations to two codes, PNNL only compared the observations to the newest code in Phase III.

All of these changes were made to minimize variability between the Phase I and Phase III analyses that could be attributed to the study methodology and that might obscure the impact of actual changes in the key items.

3.0 State Results

3.1 Field Observations

3.1.1 Key Items

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

The following key items were found applicable within the state:

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

Nearly all of the foundation observations were slab-on-grade in both Phase I and Phase III. Since Alabama has no insulation requirement for slabs under the 2015 Alabama Residential Energy Code and because there were so few observations of the other foundation types, foundation insulation is not included in this section.

3.1.1.1 Envelope Tightness

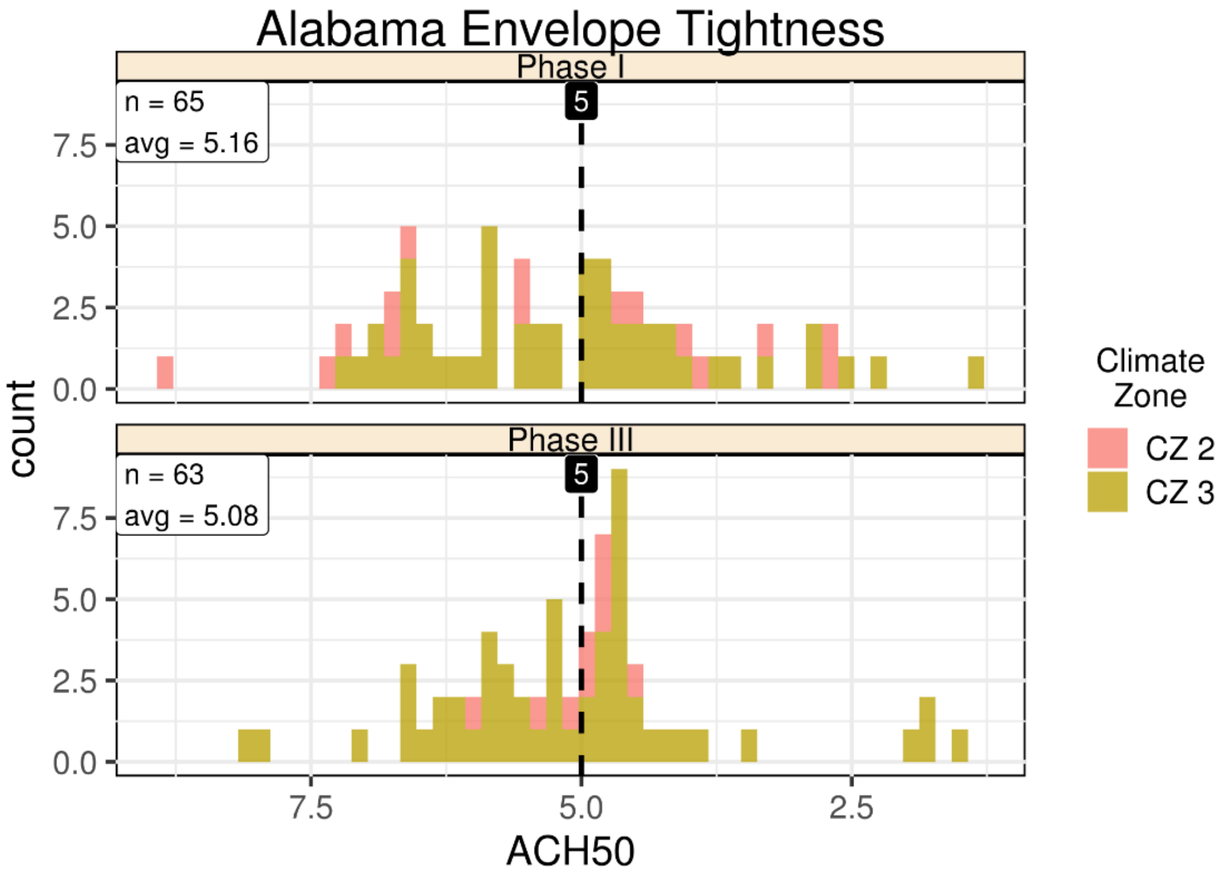

Figure 3.1. Comparison of Phase I and Phase III Envelope Tightness for Alabama

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

Envelope Tightness (ACH50)	Phase I CZ2	Phase I CZ3	Phase I Statewide	Phase III CZ2	Phase III CZ3	Phase III Statewide
Requirement	5	5	5	5	5	5
Observations						
Number	15	50	65	9	54	63
Range	8.9 to 2.65	7.25 to 1.4	8.9 to 1.4	6.1 to 4.6	8.1 to 1.6	8.1 to 1.6
Average	5.4	5.1	5.2	5.0	5.1	5.1
Compliance Rate	7 of 15 (46%)	23 of 50 (46%)	30 of 65 (46%)	6 of 9 (67%)	26 of 54 (48%)	32 of 63 (51%)

- **Interpretations:**
  - In Phase I, reductions in envelope air tightness represented an area for improvement in the state and was a focus of Phase II education and training activities.
  - Average envelope tightness marginally improved from 5.16 ACH50 in Phase I to 5.08 ACH50 in Phase III.

– The compliance rate improved modestly from 46% in Phase I to 51% in Phase III, indicating that envelope air tightness is still an area for improvement.

3.1.1.2 Window SHGC

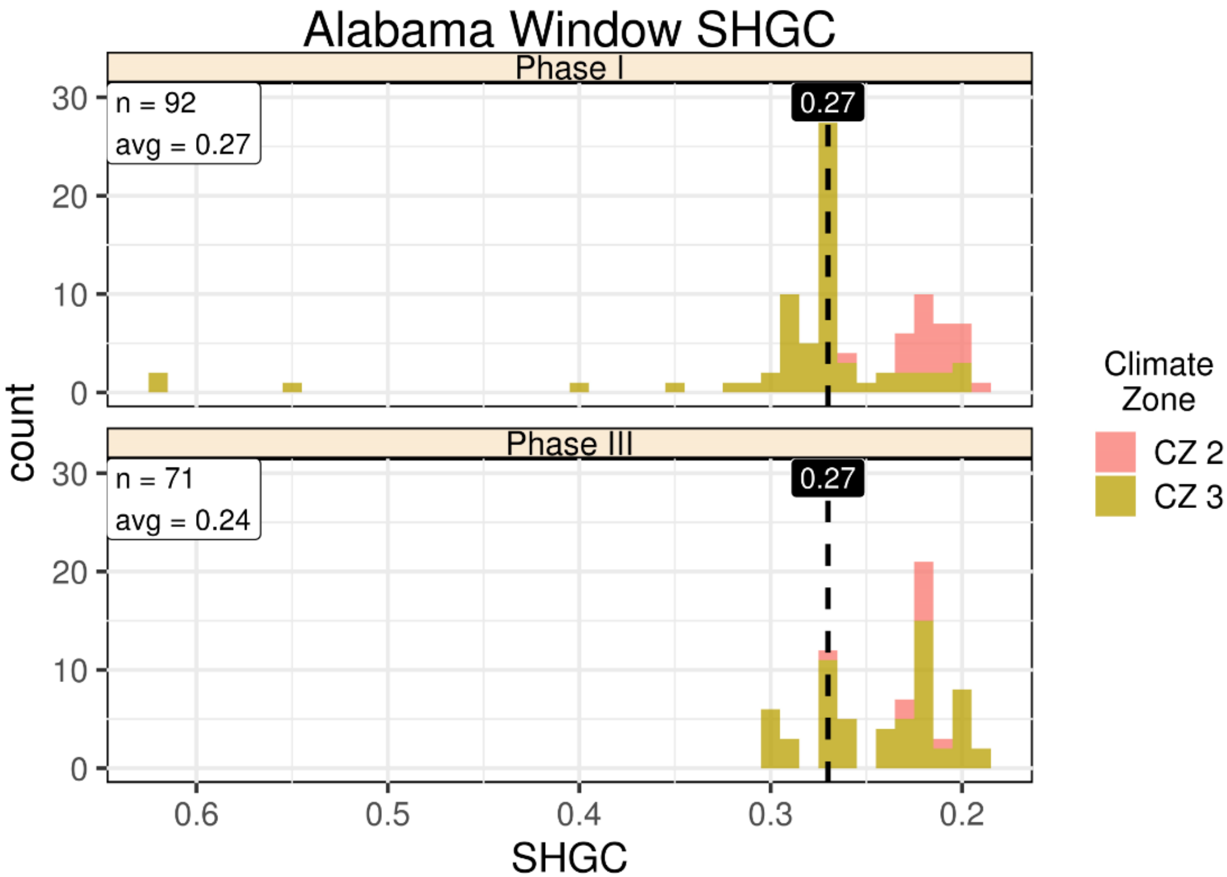

Figure 3.2. Comparison of Phase I and Phase III Window SHGC for Alabama

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

Window SHGC	Phase I CZ2	Phase I CZ3	Phase I Statewide	Phase III CZ2	Phase III CZ3	Phase III Statewide
Requirement	0.27	0.27	0.27	0.27	0.27	0.27
Observations						
Number	23	69	92	10	61	71
Range	0.26 to 0.19	0.62 to 0.2	0.62 to 0.19	0.27 to 0.21	0.3 to 0.19	0.3 to 0.19
Average	0.22	0.28	0.27	0.23	0.24	0.24
Compliance Rate	23 of 23 (100%)	45 of 69 (65%)	68 of 92 (74%)	10 of 10 (100%)	52 of 61 (85%)	6271 of 71 (87%)

- **Interpretations:**
  – All observations in Climate Zone 2 met or exceeded the requirements in both Phase I and Phase III.

– Overall, there was an improvement in SHGC between the two phases, with the majority of observations meeting or exceeding the requirements in Phase III.

3.1.1.3 Window U-Factor

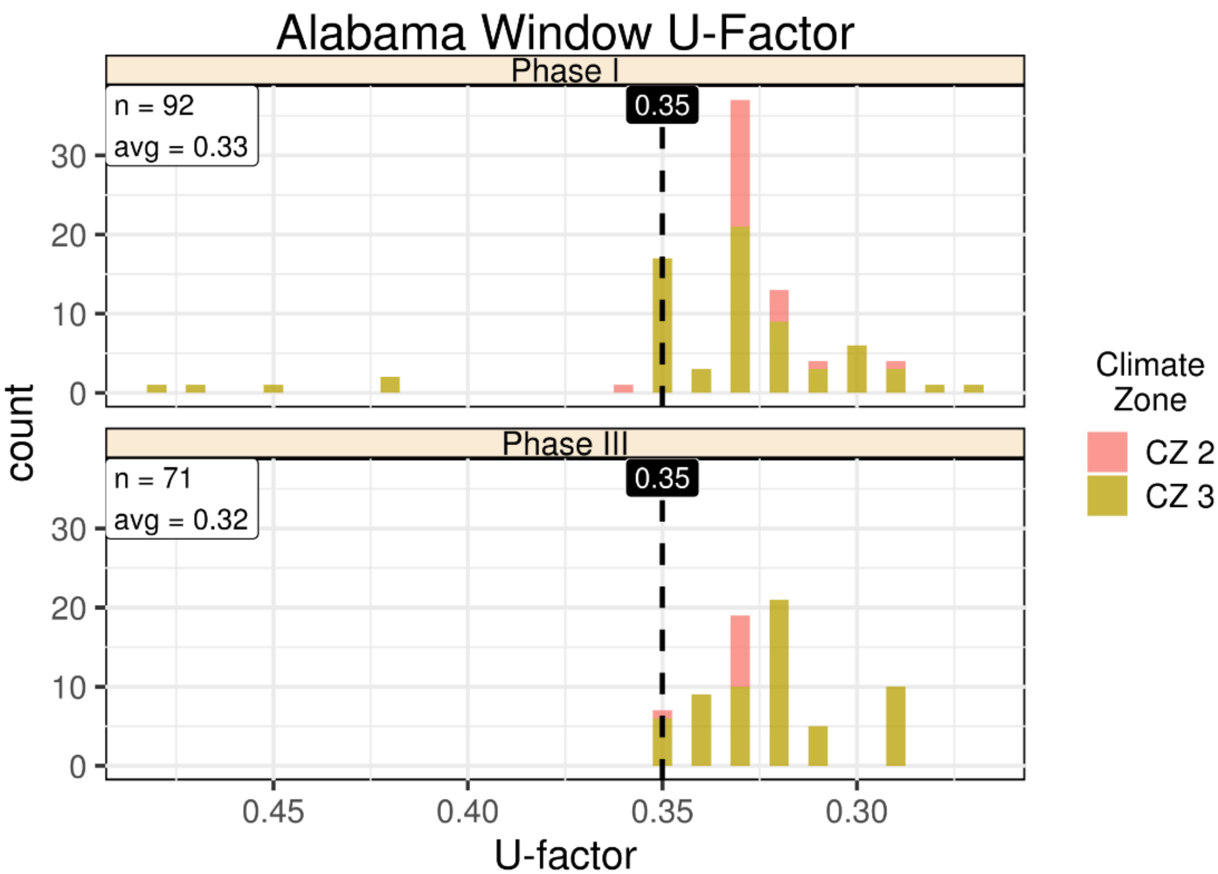

Figure 3.3. Comparison of Phase I and Phase III Window U-Factors for Alabama

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

		Phase I			**Phase III**	
Window U	**CZ2**	**CZ3**	**Statewide**	**CZ2**	**CZ3**	**Statewide**
Requirement	0.35	0.35	0.35	0.35	0.35	0.35
Observations						
Number	23	69	92	10	61	71
Range	0.36 to 0.29	0.48 to 0.27	0.48 to 0.27	0.35 to 0.33	0.35 to 0.29	0.35 to 0.29
Average	0.33	0.34	0.33	0.33	0.32	0.32
Compliance Rate	22 of 23 (96%)	64 of 69 (93%)	86 of 92 (94%)	10 of 10 (100%)	61 of 61 (100%)	71 of 71 (100%)

- **Interpretations:**
  - In Phase I, there was a high rate of compliance for fenestration products in the state, and that rate improved to 100% in Phase III.

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

3.1.1.4 Wall Insulation

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 such as combinations of cavity and continuous insulation and insulation installation quality (IIQ). 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.

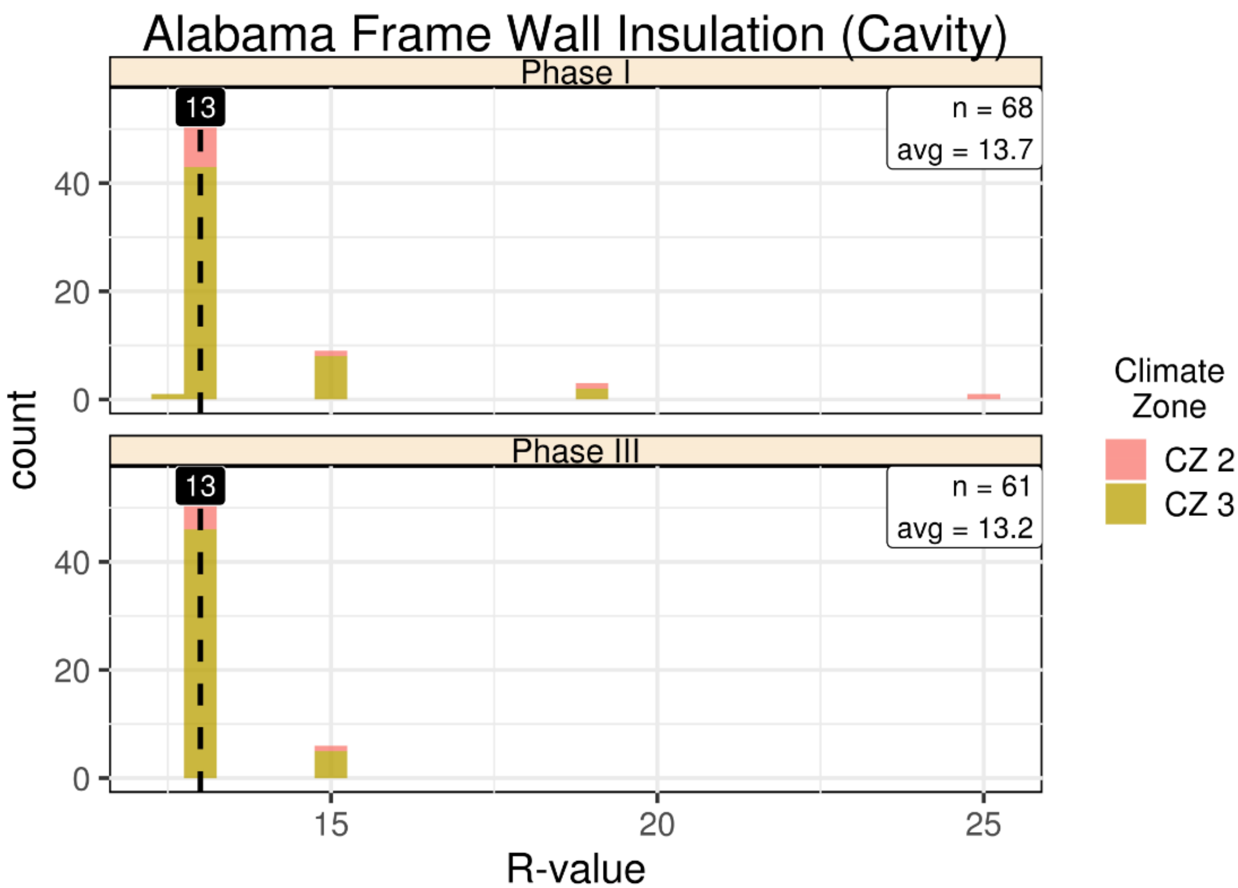

Figure 3.4. Comparison of Phase I and Phase III Wall Cavity R-Values for Alabama

Table 3.4. Alabama Wall Cavity R-Values in Phase I and Phase III

Wall R	Phase I CZ2	Phase I CZ3	Phase I Statewide	Phase III CZ2	Phase III CZ3	Phase III Statewide
Requirement	R-13	R-13	R-13	R-13	R-13	R-13
Observations						
Number	14	54	68	10	51	61
Range	R-13 to R-25	R-12.6 to R-19	R-12.6 to R-25	R-13 to R-15	R-13 to R-15	R-13 to R-15
Average	R-14.4	R-13.5	R-13.7	R-13.2	R-13.2	R-13.2
Compliance Rate	14 of 14 (100%)	53 of 54 (98%)	67 of 68 (99%)	10 of 10 (100%)	51 of 51 (100%)	61 of 61 (100%)

At the start of the overall project, IIQ was noted as a particular concern among project teams and stakeholders, as it plays an important role in the energy performance of envelope assemblies. IIQ was therefore collected by the field teams whenever possible and applied as a *modifier* in the analyses for applicable key items (i.e., wall insulation, ceiling insulation, and foundation insulation). Teams followed the RESNET[1] 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 for Phase I and Phase III. The table illustrates that above grade wall IIQ improved slightly from Phase I to Phase III, with no Grade III observations.

Table 3.5. Comparison of Phase I and Phase III Above Grade Wall IIQ for Alabama

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Above Grade Wall Observations	8 / 8	52 / 53	7 / 0	**67 / 61**
Above Grade Percentages	12% / 13%	78% / 89%	10% / 0%	**100% / 100%**

Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.5. In the graph, observations are binned for clearer presentation based on the most commonly observed combinations.

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

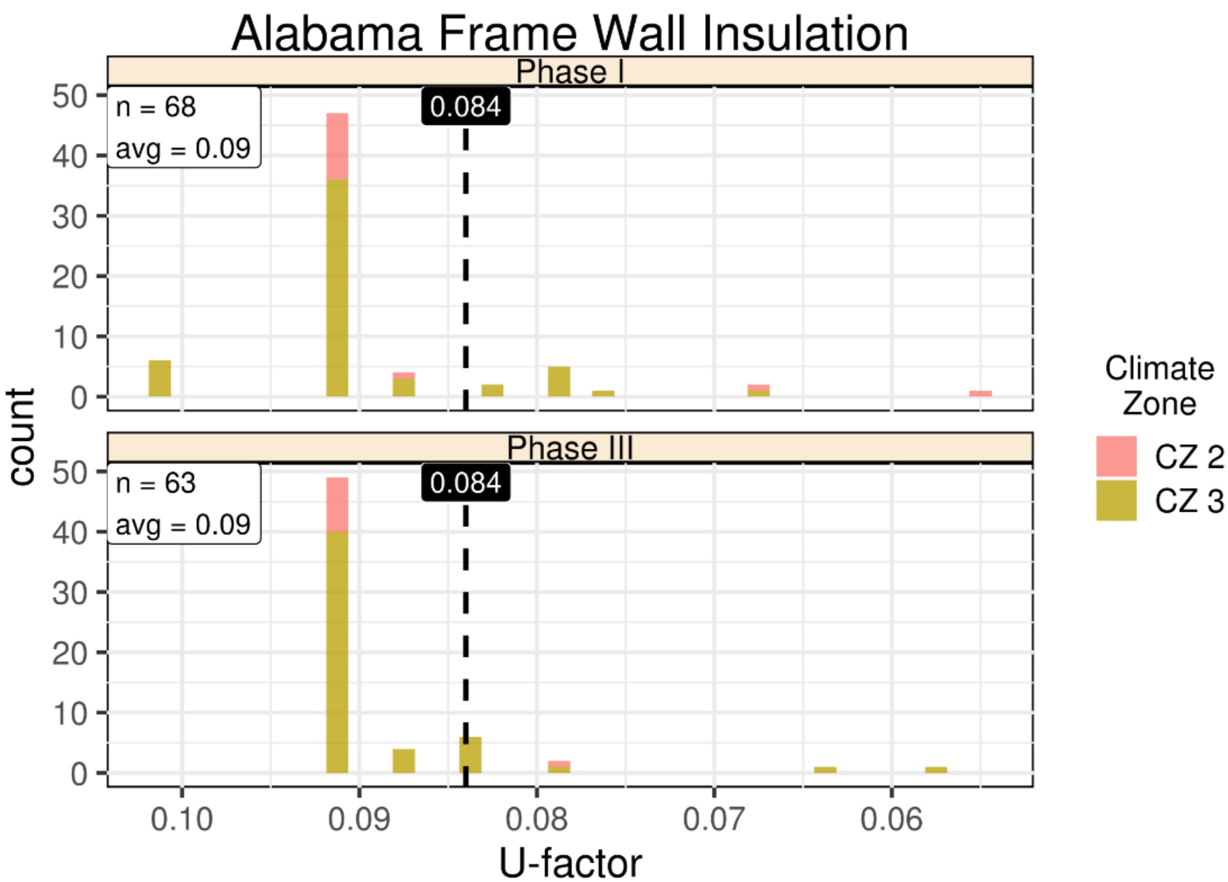

Figure 3.5. Comparison of Phase I and Phase III Wall U-Factors for Alabama

Table 3.6. Alabama Wall U-Factors in Phase I and Phase III

		Phase I			**Phase III**	
Wall U	**CZ2**	**CZ3**	**Statewide**	**CZ2**	**CZ3**	**Statewide**
Requirement	0.084	0.084	0.084	0.084	0.084	0.084
Observations						
Number	14	54	68	10	53	63
Range	0.091 to 0.054	0.102 to 0.068	0.102 to 0.055	0.091 to 0.079	0.091 to 0.057	0.091 to 0.057
Average	0.086	0.090	0.089	0.090	0.088	0.089
Compliance Rate	3 of 14 (21%)	8 of 54 (15%)	11 of 68 (16%)	1 of 10 (10%)	9 of 53 (17%)	10 of 63 (16%)

- **Interpretations:**
  - In both Phase I and Phase III, nearly 100% of the observations met or exceeded the R-value requirement. The vast majority of observations met the R-13 requirement exactly.
  - The amount of insulation does not appear to be an issue in the state. However, IIQ is an issue as shown in the lower compliance rates for Wall U-factors compared to Wall R-values. IIQ was a focus of the Phase II education and training activities, but there was no overall improvement between Phase I and Phase III, indicating IIQ is still an issue.

3.1.1.5 Ceiling Insulation

Figure 3.6 represents the observed R-values for Alabama ceilings.

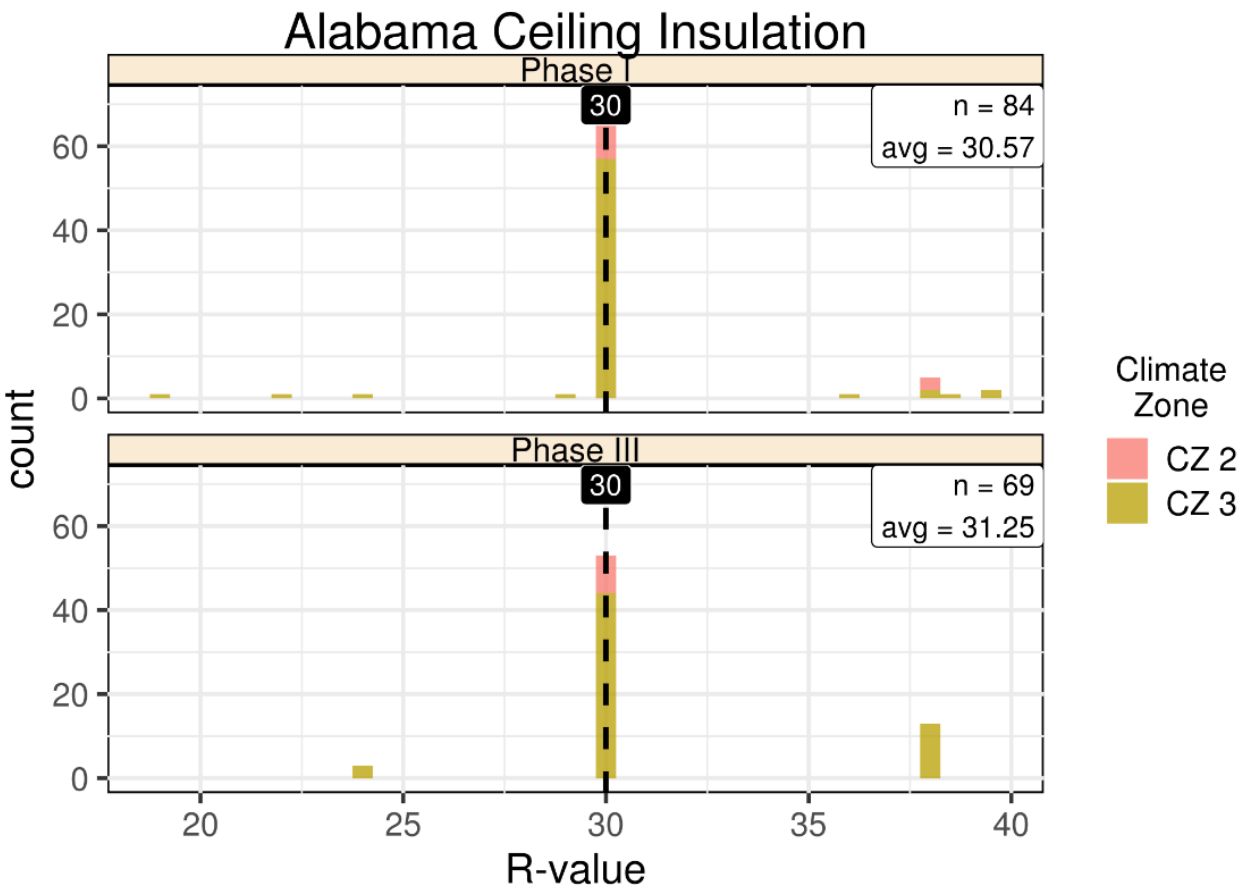

Figure 3.6. Comparison of Phase I and Phase III Ceiling R-Values for Alabama

Table 3.7. Alabama Ceiling R-Values in Phase I and Phase III

Ceiling R	Phase I CZ24	Phase I CZ3	Phase I Statewide	Phase III CZ2	Phase III CZ3	Phase III Statewide
Requirement	R-30	R-30	R-30	R-30	R-30	R-30
Observations						
Number	17	67	84	9	60	69
Range	R-30 to R-38	R-19 to R39.6	R-19 to R-39.6	R-30	R-24 to R-38	
Average	31	30	31	30	31	31
Compliance Rate	17 of 17 (100%)	63 of 67 (93%)	80 of 84 (95%)	9 of 9 (100%)	57 of 60 (95%)	66 of 69 (96%)

Table 3.8 shows the number and percentage of IIQ observations by grade for roof cavity insulation for Phase I and Phase III. The table illustrates that roof cavity IIQ improved greatly from Phase I to Phase III.

Table 3.8. Comparison of Phase I and Phase III Roof IIQ for Alabama

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Roof Cavity Observations	58 / 63	19 / 4	2 / 0	**79 / 67**
Roof Cavity Percentages	73% / 94%	24% / 6%	3% / 0%	**100% / 100%**

Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.7.

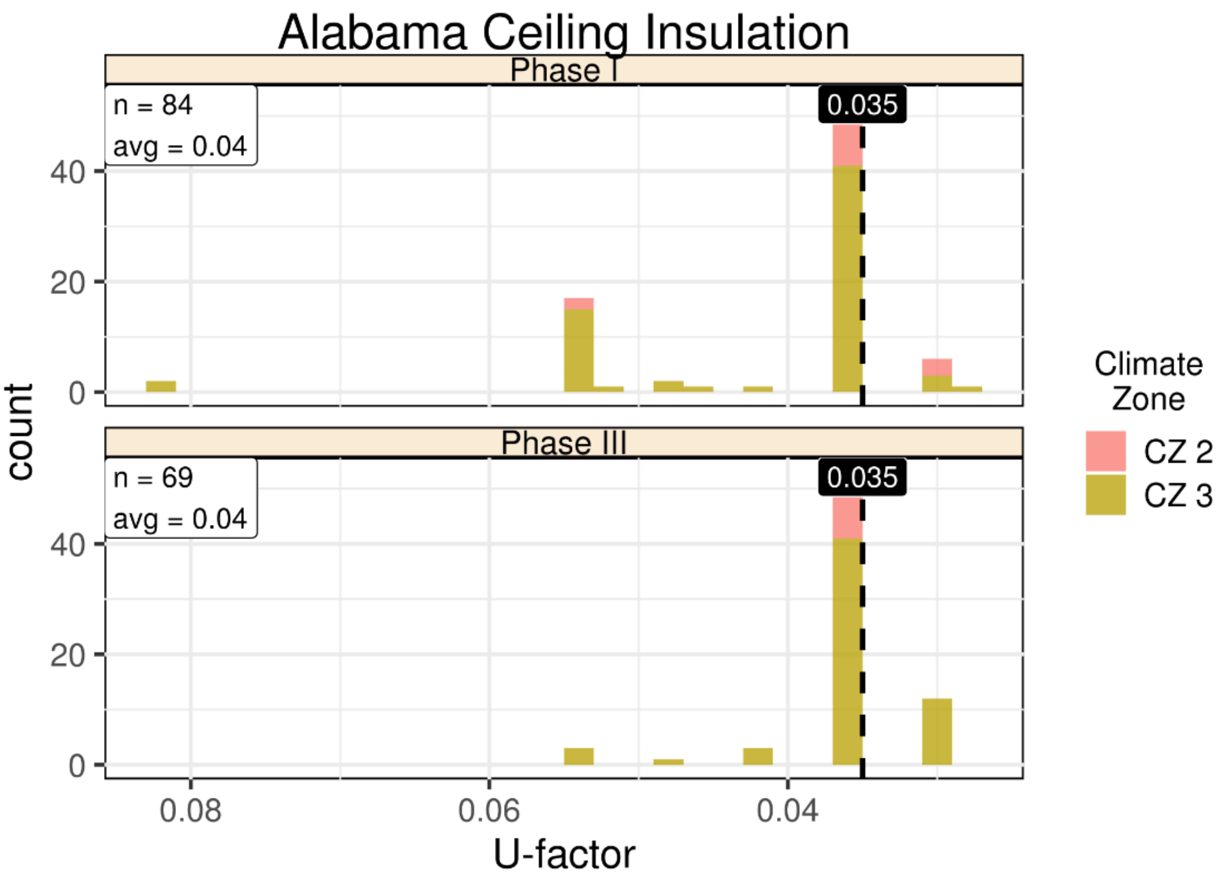

Figure 3.7. Comparison of Phase I and Phase III Ceiling U-Factors for Alabama

Table 3.9. Alabama Ceiling U-Factors in Phase I and Phase III

Ceiling U	Phase I CZ2	Phase I CZ3	Phase I Statewide	Phase III CZ2	Phase III CZ3	Phase III Statewide
Requirement	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035
Observations						
Number	17	67	84	9	60	69
Range	0.054 to 0.029	0.081 to 0.029	0.081 to 0.029	0.044 to 0.044	0.055 to 0.036	0.055 to 0.036
Average	0.036	0.041	0.040	0.044	0.043	0.043
Compliance Rate	15 of 17 (88%)	48 of 67 (72%)	63 of 84 (75%)	9 of 9 (100%)	52 of 60 (87%)	61 of 69 (88%)

- **Interpretations:**
  - The majority of R-value observations met the code requirement exactly in both Phase I and Phase III.
  - Overall, the amount of ceiling insulation does not appear to be an issue in the state. In addition, the majority of IIQ observations in Phase I were Grade I; Phase III had even more observations noted as Grade I, and therefore more observations met or exceeded the U-factor requirements.

3.1.1.6 Lighting

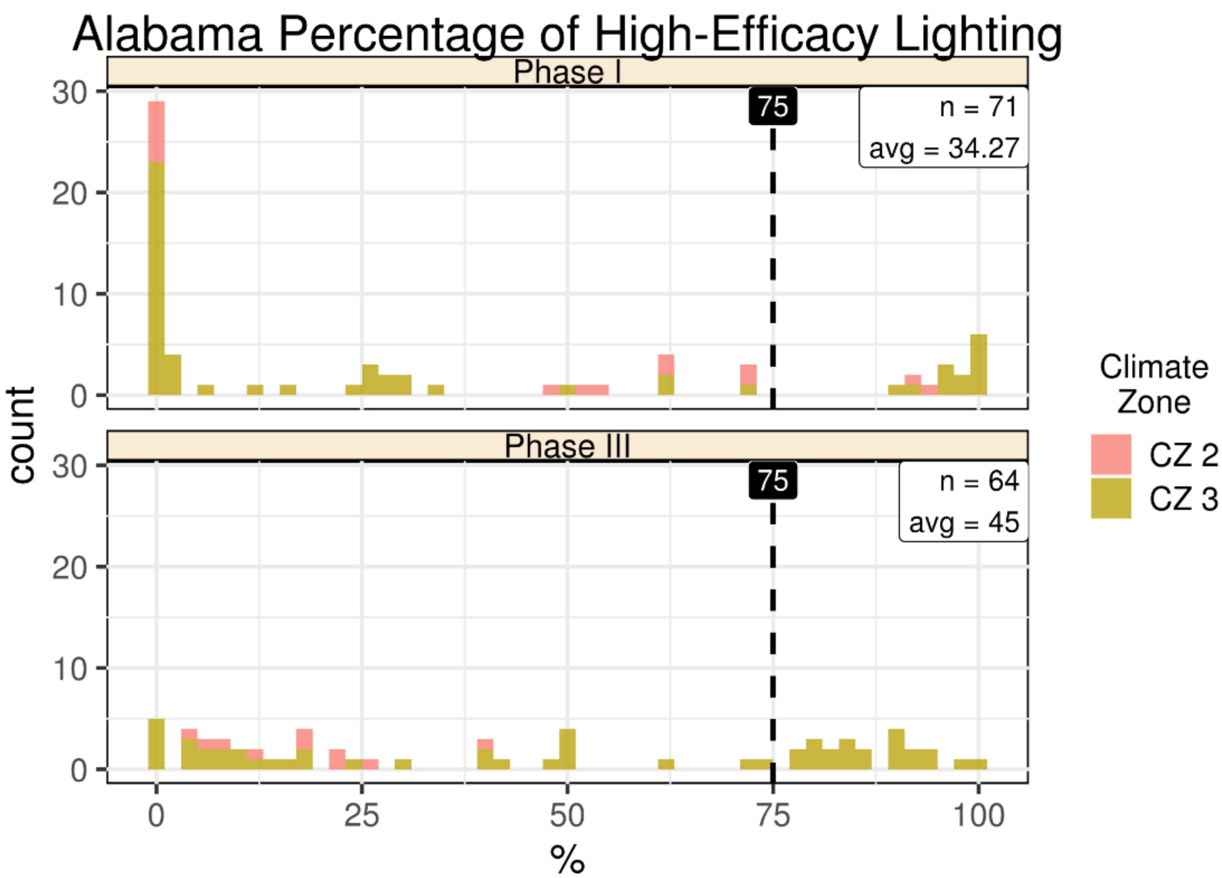

Figure 3.8. Comparison of Phase I and Phase III High-Efficacy Lighting Percentages for Alabama

Table 3.10. Alabama High-Efficacy Lighting in Phase I and Phase III

Lighting	Phase I CZ2	Phase I CZ3	Phase I Statewide	Phase III CZ2	Phase III CZ3	Phase III Statewide
Requirement	75	75	75	75	75	75
Observations						
Number	15	56	71	9	54	63
Range	0 to 94	0 to 100	0 to 100	5 to 26	0 to 100	0 to 100
Average	41	33	34	15	50	45
Compliance Rate	4 of 15 (27%)	13 of 56 (23%)	15 of 71 (21%)	0 of 9 (0%)	23 of 54 (43%)	23 of 63 (37%)

- **Interpretations:**
  - Overall, in Phase I less than one-quarter of the field observations met the requirement; a much lower number than expected. This represented an area of significant savings potential and was a focus of Phase II education and training activities.
  - The average statewide percentage of high-efficacy lighting and the compliance rate increased in Phase III, but the compliance rate is still low. Lighting continues to represent an area of significant savings potential.

3.1.1.7 Duct Tightness

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

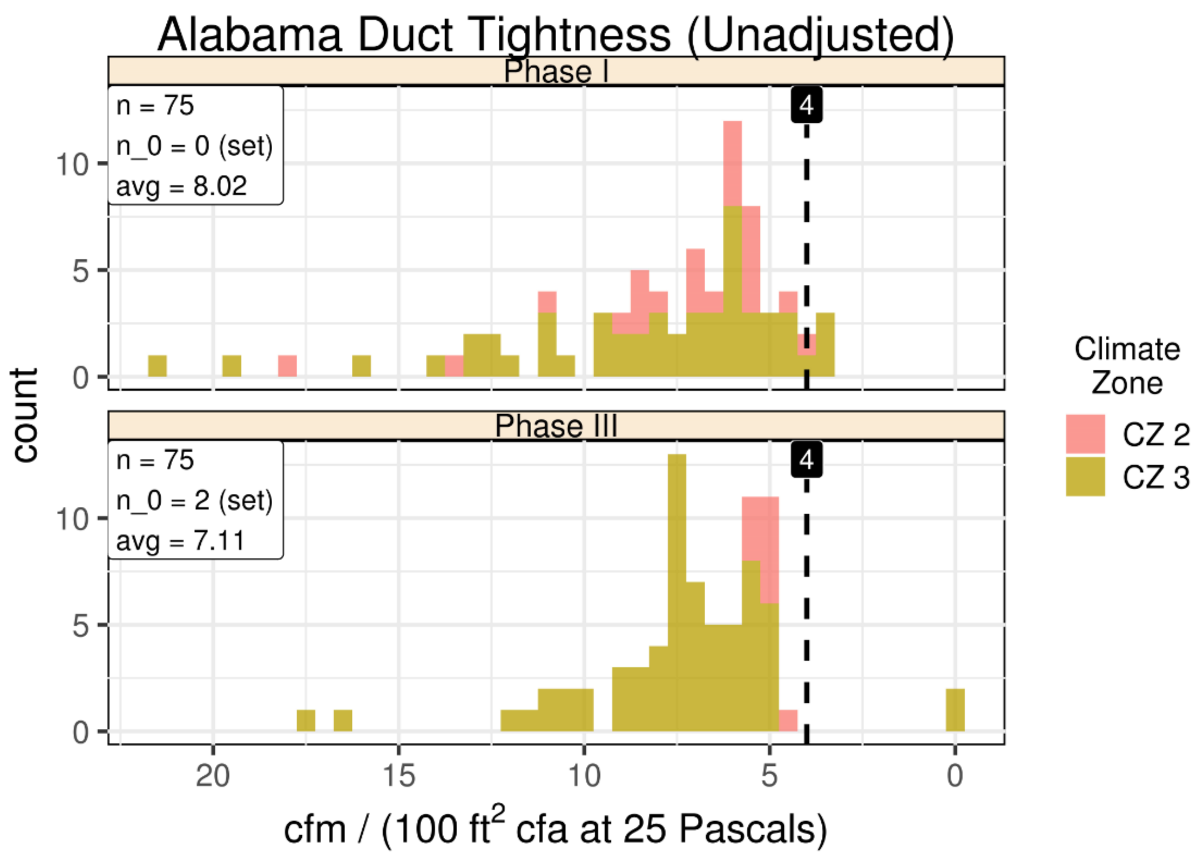

Figure 3.9. Comparison of Phase I and Phase III Duct Tightness Values for Alabama[2]

[2] Note that the Phase III data for Alabama includes two observations of ducts with an unadjusted duct tightness of "0". These duct tightness observations include comments on the original data collection forms of "Could not get a reading - too leaky". Note also in the Phase I data for Alabama, an additional eight observations of duct tightness were from homes with two duct systems. The Phase I analysis did not address data with multiple duct tightness values.

Table 3.11. Alabama Duct Tightness Values in Phase I and Phase III (unadjusted)

Duct Tightness (Unadjusted)	Phase I CZ2	Phase I CZ3	Phase I Statewide	Phase III CZ2	Phase III CZ3	Phase III Statewide
Requirement	4	4	4	4	4	4
Observations						
Number	23	52	75	9	66	75
Range	18.1 to 4.2	21.3 to 3.5	21.3 to 3.5	4.7 to 5.5	0 to 17.6	0 to 17.6
Average	7.5	8.3	8.1	5.2	7.4	7.1
Compliance Rate	0 of 23 (0%)	3 of 52 (6%)	3 of 75 (4%)	0 of 9 (0%)	2 of 66 (3%)	2 of 75 (3%)

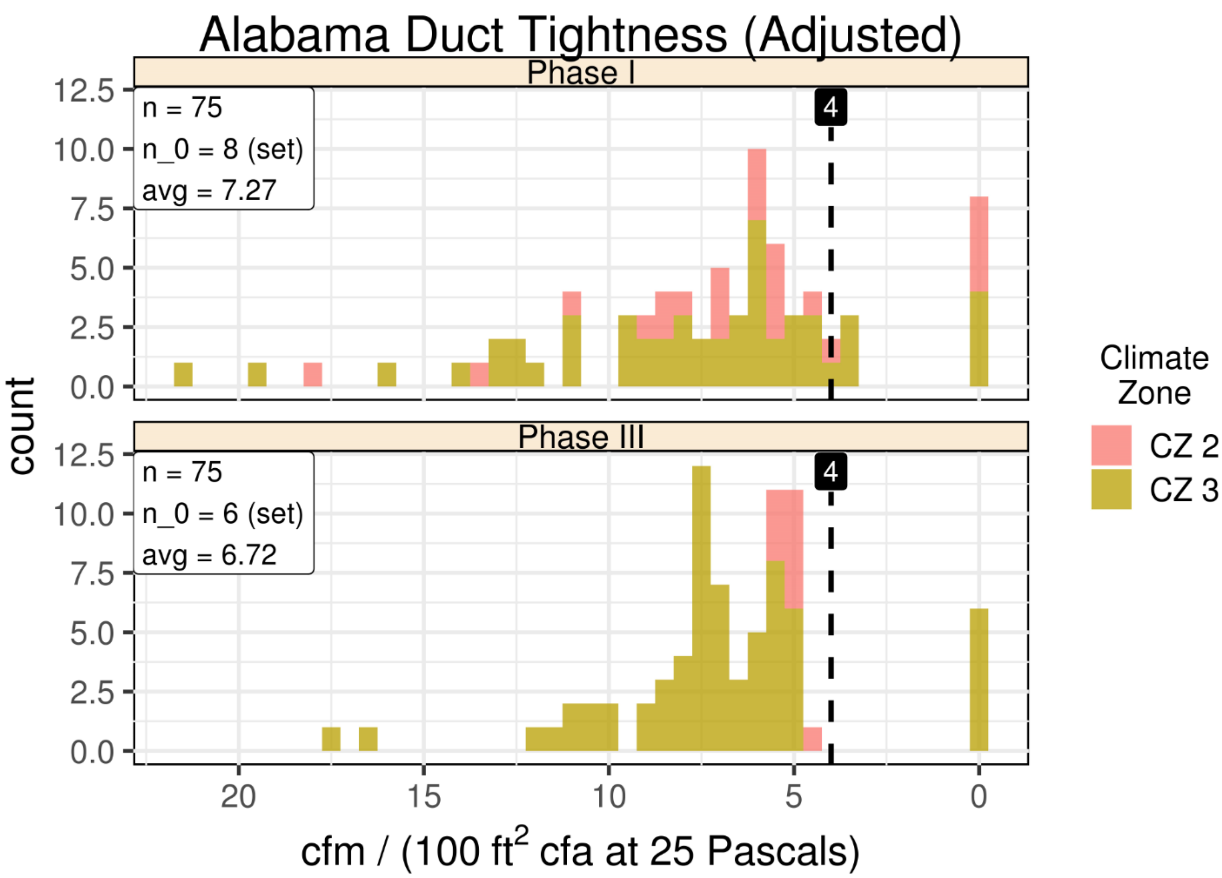

Figure 3.10. Comparison of Phase I and Phase III Duct Tightness (Adjusted)Values for Alabama

Table 3.12. Alabama Duct Tightness Values in Phase I and Phase III (Adjusted)[3]

Duct Tightness (Adjusted)	Phase I CZ2	Phase I CZ3	Phase I Statewide	Phase III CZ2	Phase III CZ3	Phase III Statewide
Requirement	4	4	4	4	4	4
Observations						
Number	23	52	75	9	66	75
Range	0 to 18.1	0 to 21.3	0 to 21.3	4.7 to 5.5	0 to 17.6	0 to 17.6
Average	6.3	7.7	7.3	5.2	6.9	6.7
Compliance Rate	4 of 23 (17%)	7 of 52 (13%)	11 of 75 (15%)	0 of 9 (0%)	6 of 66 (9%)	6 of 75 (8%)

- **Interpretations:**
  - Unadjusted duct tightness was poor in both Phase I and Phase III, with Phase III being worse. The same trend was seen in adjusted duct tightness where the majority of homes were compliant due to ducts being entirely in conditioned space.

3.1.2 Additional Data Items

The project team collected data on all code requirements within the state as well as other items to inform the energy simulation and analysis for the project (e.g., home size, installed equipment systems, etc.). While these items were not the focal point of the study, and many are not considered statistically representative, they do provide some insight surrounding the energy code and residential construction within the state, 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. A larger selection of the additional data items collected as part of the Alabama field study is contained in Appendix C. The full data set is also available on the DOE Building Energy Codes Program website.[4]

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

3.1.2.1 Average Home

Table 3.13. Average Home

Home Statistics	Phase I	Phase III
Average square footage (ft^2)	2552	2227
Number of Stories	1.52	1.4

3.1.2.2 Compliance

In Phase I, none of the homes participated in an above-code program. In Phase III, 2 of the 126 homes (1.6%) were identified as Energy Star homes.

[3] See previous footnote on unadjusted duct tightness observations.
[4] Available at https://www.energycodes.gov/residential-energy-code-field-studies.

3.1.2.3 Envelope

Table 3.14. Envelope

Requirement	Phase I	Phase III
Profile		
Walls	All wood-framed with mix of 4" (93%) and 6" (7%) (n=132)	All wood-framed (stud size NA) (n=122)
Foundations	n=134	n=126
Basement	5%	1%
Slab-on-grade	90%	98%
Floors	5%	1%
Insulation labeled	77% (n=90)	100% (n=63)
Lighting fixtures sealed	81% (n=104)	99% (n=75)
Utility penetrations sealed	80% (n=108)	78% (n=83)
Attic hatches and doors complied	17% (n=47)	26% (n=35)
Attic access openings sealed	35% (n=56)	55% (n=44)
Envelope areas behind tubs and showers	53% (n=60)	75% (n=61)
Openings around doors and windows	97% (n=61)	97% (n=62)

3.1.2.4 Duct & Piping Systems

Table 3.15. Duct and Piping Systems

Requirement	Phase I	Phase III
Profile		
Supply ducts located within conditioned space (percentage of duct system)	17% (n=107)	16% (n=152)
Return ducts located within conditioned space (percentage of duct system)	24 % (n= 115)	16.5% (n=152)
Supply ducts entirely within conditioned space (percentage of homes and number)	11 % (12 homes)	4% (6 homes)
Return ducts entirely within conditioned space (percentage of homes and number)	19 % (22 homes)	8% (12 homes)
Duct Insulation	R- 8.0 (n=278)	R-7.9 (n=233)
Pipe Insulation	R- 2.3 (n= 120)	R-2.8 (n=100)
Building cavities not used as supply ducts	97% (n= 116)	99% (n=99)

Requirement	Phase I	Phase III
Air handlers sealed	82% (n= 113)	98% (n=112)
Filter boxes sealed	77% (n= 106)	90% (n=118)

Successes and Improvement

As a percentage of compliant observations, successes include insulation labeling and sealing of lighting fixtures. Areas identified for improvement in Phase I, air handlers sealed and filter boxes sealed, improved in Phase III. Areas that could still use improvement include attic hatches and doors and attic openings.

3.1.2.5 HVAC Equipment

Table 3.16. HVAC Equipment

Requirement	Phase I	Phase III
Profile		
Heating equipment type	Mostly electric heat pumps with remainder gas furnaces (n=127, 45 gas furnace, 73 electric heat pump, 3 electric furnace, 4 electric resistance strip heat, 2 gas heat pump)	Majority heat pumps (n=152, 57 gas furnace, 94 electric heat pump, 1 electric resistance strip heat, and 2 electric furnace)
Heating equipment efficiency	83 AFUE furnace, 8.3 HSPF electric heat pump (n=80 total)	Not collected
Cooling equipment type	Majority heat pumps (n=125,84 heat pump, 39 central AC, 2 air conditioner)	Not collected
Cooling equipment efficiency	13.3 SEER	Not collected
Water heating equipment type	Mostly electric storage (n=116, 53 electric storage (1 heat pump), 33 gas storage, 28 gas tankless, 2 electricity tankless)	Mostly electric storage (n=98, 54 electric storage, 33 gas storage, and 11 gas tankless)
Water heating equipment capacity	52 gallons (n=61)	52 gallons (n=66)[5]
Water heating equipment efficiency	EF 0.82 (n=61, value is for all reported EF below 1. There is also one observation of 2.4 for the heat pump water heater.)	EF 0.80 (n=46)

3.2 Energy Use Intensity

The statewide energy analysis results in Figure 3.11 show an estimated decrease in EUI between Phase I and Phase III of 0.77 kBtu/ft^2, short of the 1.25 kBtu/ft^2 threshold for statistically significant savings. The observed data set (as gathered in the field) was compared against the same set of homes meeting prescriptive code requirements. Average energy consumption decreased by over 4% between Phase I and Phase III. Table 3.17 compares the Phase I and Phase III results.

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

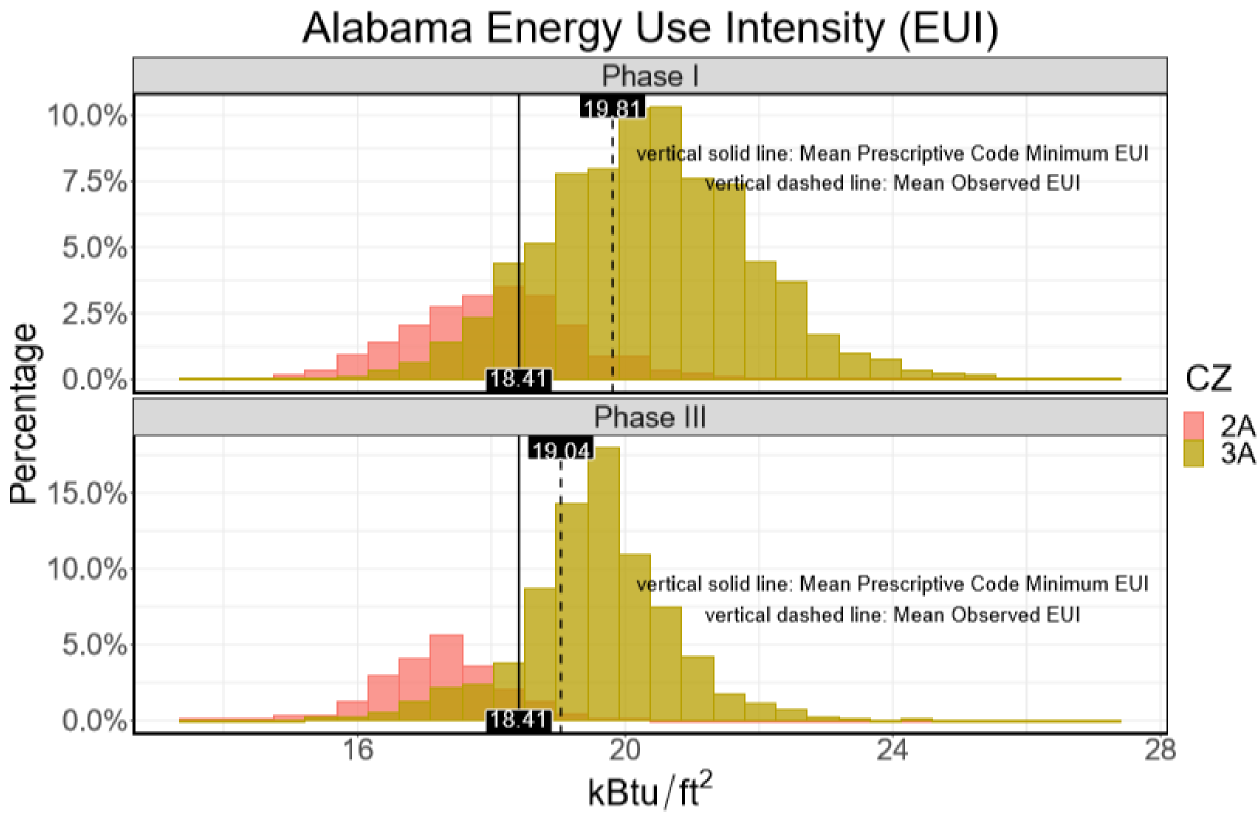

Figure 3.11. Comparison of Phase I and Phase III Statewide EUI for Alabama

Table 3.17. Alabama Statewide EUI in Phase I and Phase III

Prescriptive EUI[6]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
18.41	19.81	+7.6%	19.04	+3.4%	-3.9%

3.3 Savings Potential

Several key items in Phase I were previously identified as targets for improvements via education, training and compliance-improvement initiatives. Those with the greatest potential[7], shown below followed by the percent that met code, were further analyzed to estimate the associated savings potential for energy, cost and environmental impacts.

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

[7] Defined here as those with less than 85% of observations meeting the prescriptive code requirement

Table 3.18. Comparison of Phase I and Phase III Compliance Rates by Measure in Alabama

Measure	Phase I Compliance Rate	Phase III Compliance Rate	Phase III to Phase I Difference in Compliance Rate
Duct Tightness[8]	15%	8%	-7%
Lighting	21%	37%	+16%
Envelope Air Tightness	46%	51%	+5%
Exterior Wall Insulation	16%	16%	0%
Window SHGC	74%	87%	+13%

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

The results for the energy, cost, and environmental savings potential estimates are shown in Table 3.19. The results indicate that the Phase II education and training activities were successful in reducing the overall savings potential for all measures. Improvement is measured by a reduction in measure-level savings potential between Phase I and Phase III.

Table 3.19. Comparison of Phase I and Phase III Estimated Annual Statewide Savings Potential

	Potential Total Energy Savings (MMBtu)		Potential Total Energy Cost Savings ($)		Potential Total State Emissions Reduction (MT CO2e)	
Measure	**Phase I**	**Phase III**	**Phase I**	**Phase III**	**Phase I**	**Phase III**
Duct Tightness	14,420	11,785	395,063	323,238	2,272	1,874
Lighting	10,891	8,203	385,451	290,649	2,408	1,847
Envelope Air Tightness	11,207	7,883	263,089	185,084	1,417	996
Exterior Wall Insulation	8,022	6,983	201,105	175,080	1,116	975
Window SHGC	1,309	97	54,674	4,534	356	261
TOTAL	**45,849**	**34,951**	**$1,299,382**	**$978,585**	**7,569**	**5,692**

Overall measure-level energy cost savings potential showed a 25% reduction between Phase I and Phase III. To reflect the longer-term cost savings potential of improved compliance, annual savings were accumulated over 5, 10, and 30 years of new construction (Table 3.20). See Appendix D for additional details on electricity savings and natural gas savings per home associated with each measure; savings by individual foundation components; and total savings and environmental reductions accumulated over 5, 10, and 30 years of construction.

[8] This compliance rate is only for ducts that are not 100% in conditioned space.

Table 3.20. Comparison of Five-year, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Potential Phase III vs. Phase I

	Potential Total Energy Cost Savings ($) 5 yr		Potential Total Energy Cost Savings ($) 10 yr		Potential Total Energy Cost Savings ($) 30 yr	
Measure	**Phase I**	**Phase III**	**Phase I**	**Phase III**	**Phase I**	**Phase III**
Duct Tightness	5,925,945	4,848,565	21,728,465	17,778,071	183,704,295	150,305,510
Lighting	5,781,765	4,359,739	21,199,805	15,985,710	179,234,715	135,151,913
Envelope Air Tightness	3,946,335	2,776,259	14,469,895	10,179,615	122,336,385	86,064,021
Exterior Wall Insulation	3,016,575	2,626,203	11,060,775	9,629,410	93,513,825	81,412,287
Window SHGC	820,100	68,010	3,007,070	249,370	25,423,410	2,108,310
TOTAL	**19,490,730**	**14,678,776**	**71,466,010**	**53,822,176**	**604,212,630**	**455,042,041**

4.0 Conclusions

Alabama's field study achieved modest code compliance improvements, which equate to higher potential energy performance of new residential homes. Although the Alabama field study was trending the right way with a reduction in measure-level savings potential, the change was not considered statistically significant at 0.77 kBtu/ft^2.

It should be noted that Alabama's energy code was updated during the course of the study. At the start of Phase I, the state energy code was based on the 2009 IECC with some amendments. Later in the study, the state adopted a new code based on the 2015 IECC with some amendments. All Phase I data in this study was collected from homes permitted under the 2009 code; potential savings, however, were estimated against the 2015 code, as that is the code that homes would need to comply with in the future, and that was the focus of the education and training in the state. Phase III data was collected in homes permitted under the 2015 Alabama Residential Energy Code. All of the results noted in this report are based on the 2015 code.

Based on this study's findings, a prototypical, newly constructed home in Alabama consumes more energy than a home exactly meeting the state energy code. The average home, however, showed an estimated improvement in energy performance of nearly 4 percent between Phase I and III (Table 4.1).

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

Prescriptive EUI[1]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
18.41	19.81	-7.6%	19.04	-3.4%	-3.9%

This results in over $320,000 in annual achieved savings, an improvement of 25% following the Phase II targeted education and training activities as shown in Table 4.2.[2] The contributing factor to the reduction in measure-level savings potential was improvements in all key items: envelope air tightness, ceiling insulation, exterior wall insulation, and lighting, with lighting having a particularly positive change.

Table 4.2. Estimated Annual Statewide Cost Savings Potential

	% Change
Measure	**Phase III vs. I**
Duct Tightness	-18.1%
Lighting	-24.6%
Envelope Air Tightness	-29.6%
Exterior Wall Insulation	-12.9%
Window SHGC	-91.7%
TOTAL	**-24.7%**

[1] Calculated based on the minimum prescriptive requirements of the state energy code.
[2] See Table 3.19 for potential total energy cost savings in each phase.

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

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*. https://www.energycodes.gov/sites/default/files/2020-06/NationalResidentialCostEffectiveness_2009_2012.pdf

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

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

EnergyPlus. https://energyplus.net/.

The Alabama residential field study website is available at http://www.alenergycode.org/ (accessed May 21, 2020).

Institute for Market Transformation (IMT) information on the Alabama residential energy code field study is available at https://www.imt.org/how-we-drive-demand/building-energy-codes/alabama-residential-energy-code-field-study/ (accessed May 21, 2020).

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

Appendix A

Stakeholder Participation

Appendix A

Stakeholder Participation

Table A.1. Stakeholder Participation in Project Kickoff Meeting

Stakeholder	Description
Home Builders Association of Alabama (HBAA)	Trade organization representing builders, remodelers, developers and affiliated professionals.
Southeast Energy Efficiency Alliance (SEEA)	Regional energy efficiency advocacy organization.
Alabama Department of Economic and Community Affairs (ADECA)	State agency responsible for overseeing adoption of the energy and residential building codes.
Code Officials Association of Alabama (COAA)	A charter chapter of the International Code Council.
Shelby County – Permits and Inspections	Government agency responsible for local code administration and enforcement in Shelby County.
Tuscaloosa Inspection Department	Government agency responsible for local code administration and enforcement in Tuscaloosa.
Lee County Building Inspection	Government agency responsible for local code administration and enforcement in Lee County.
Alabama Board of Heating, Air Conditioning, & Refrigeration Contractors	State board responsible for the oversight of heating, air conditioning and refrigeration contractors.
Alabama Energy and Residential Codes Board,	State board, administered by ADECA, with the responsibility of adopting statewide residential and commercial energy codes.
Central Alabama Electric Cooperative	A not-for-profit, member-owned electric distribution utility serving more than 42,000 meters in a 10-county area of central Alabama.
Home Builders Licensure Board	The Board enforces the provisions of The Home Building and Home Improvement Industries Act that provides for the licensure of persons engaged in residential construction in the State of Alabama.
Alabama General Contractors Board	The Board licenses and regulates commercial/industrial contractors in the major and specialty classifications that constitute the industry. Currently there are more than 10,000 general contractors licensed to work in the state.

Appendix B

State Sampling Plan

Appendix B

State Sampling Plan

B.1 State Sampling Plan

Table B.1. Phase I State Sampling Plan

Location (City, County)	Sample	Actual
Huntsville, Madison	6	6
Madison County Unincorporated Area, Madison	3	3
Mobile County Unincorporated Area, Mobile	7	7
Auburn, Lee	5	5
Baldwin County Unincorporated Area, Baldwin	2	2
Hoover, Jefferson	2	2
Tuscaloosa, Tuscaloosa	7	7
Madison, Madison	5	5
Montgomery, Montgomery	2	2
Fairhope, Baldwin	1	1
Jefferson County Unincorporated Area, Jefferson	1	1
Dothan, Houston	1	1
Foley, Baldwin	1	1
Opelika, Lee	2	2
Phenix City, Russell	1	1
Vestavia Hills, Jefferson	3	3
Pell City, St. Clair	1	1
Mobile, Mobile	1	1
Shelby County Unincorporated Area, Shelby	1	1
Millbrook, Elmore	1	1
Athens, Limestone	1	1
Helena, Shelby	1	1
Moody, St. Clair	1	1
Saraland, Mobile	2	2
Troy, Pike*	1	1
Pelham, Shelby	1	1
Wetumpka, Elmore	1	1
Cullman, Cullman	1	1
Irondale, Jefferson	1	1
Total	**63**	**63**

*Enterprise in Coffee County substituted for Troy in Pike County

Table B.2. Phase III State Sampling Plan

Location (City, County)	Sample	Actual
Huntsville, Madison County	7	7
Madison County Unincorporated Area, Madison County	4	4
Auburn, Lee County	7	7
Madison, Madison County	4	4
Baldwin County Unincorporated Area, Baldwin County	1	1
Mobile County Unincorporated Area, Mobile County	2	2
Hoover, Jefferson County	2	2
Fairhope, Baldwin County	4	4
Tuscaloosa, Tuscaloosa County	5	5
Jefferson County Unincorporated Area, Jefferson County	2	2
Pike Road Town, Montgomery County	4	4
Trussville, Jefferson County	2	2
Lee County Unincorporated Area, Lee County	4	4
Daphne, Baldwin County	1	1
Helena, Shelby County	2	2
Chelsea, Shelby County*	1	1
Calera, Shelby County*	1	1
Shelby County Unincorporated Area, Shelby County	1	1
Northport, Tuscaloosa County	1	1
Pelham, Shelby County	1	1
Vestavia Hills, Jefferson County	1	1
Athens, Limestone County	1	1
Mobile, Mobile County	1	1
Phenix City, Russell County	1	1
Enterprise, Coffee County	1	1
Cullman, Cullman County	1	1
Wetumpka, Elmore County	1	1
Total	**63**	**63**

* No local permitting; permits pulled from county within those jurisdictions

B.2 Substitutions

In the Alabama Phase I study, the project team had to make one substitution in the final sampling plan, substituting Enterprise in Coffee County for Troy in Pike County. This was due to an inability to obtain permit data from a single jurisdiction selected in the random sample. The project team discussed this challenge, and ultimately identified an adequate alternative (i.e., a jurisdiction in the same region of the state with a similar population, residential construction starts and socio-economic conditions). There were no substitutions in Phase III.

Appendix C

Additional Data

Appendix C

Additional Data

C.1 Additional Data Collected by Field Teams

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

The following is a sampling of the additional data items collected as part of the Alabama field study. Each item is presented, along with a brief description and statistical summary based on the associated field observations. The full data set is available on the DOE Building Energy Codes Program website.[1]

C.1.1 General

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

C.1.1.1 Average Home

Table C.1. Home Size

Home Statistics	Phase I	Phase III
Average Square Footage (ft^2)	2252	2245
Number of Stories	1.5	1.4
Number of Homes Visited	134	125

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

Conditioned Floor Area (ft^2)	< 1000	1000 to 1999	2000 to 2999	3000 to 3999	4000+
Percentage (Phase I)	0%	33%	43%	15%	9%
Percentage (Phase III)	0%	44%	39%	14%	2%

Table C.3. Number of Stories

No. of Stories	1	2	3	4+
Percentage (Phase I)	50%	49%	1%	0%
Percentage (Phase III)	62%	37%	0%	1%

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

C.1.1.2 Wall Profile

Table C.4. Wall Characteristics

Wall Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Framing Type			134	122
Frame Walls	100%	100%		
Mass Walls	0%	0%		
Framing Material			134	122
Wood	100%	100%		
Framing Depth			134	NA
4 inch	93%	NA		
6 inch	7%	NA		
Type of Wall Insulation			68	61
Cavity Only	100%	100%		
Cavity + Continuous	0%	0%		
Continuous Only	0%	0%		

C.1.1.3 Foundation Profile

Table C.5. Foundation Characteristics

Foundation Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Foundation Type			134	125
Basement	5%	1%		
Slab on Grade	90%	98%		
Crawlspace	5%	1%		
Basement Type			7	2
Conditioned	71%	100%		
Unconditioned	29%	0%		

C.1.2 Compliance

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

Table C.6. Energy Code and Above Code Programs

Code or Above Code Program Used	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Energy Code Used			3	126
2009 IECC	67%	0%		
2015 IECC	0%	100%		
Was home participating in an above code program[2]?			16	4
Yes	0	50%		
No	100%	50%		

C.1.3 Envelope

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

Table C.7. Thermal Envelope Characteristics

Thermal Envelope Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Was insulation labeled?			90	63
Yes	77%	100%		
No	23%	0%		
Did the attic hatch/door exhibit the correct insulation value?			47	35
Yes	7%	26%		
No	93%	74%		
Air Sealing in accordance with checklist[3]				
Thermal Envelope sealed?	48%	33%	69	63
Fenestration Sealed?	94%	100%	18	7
Openings around doors and windows sealed?	97%	97%	61	62
Utility penetrations sealed?	80%	78%	108	28
Dropped ceilings sealed?	36%	61%	56	28
Knee walls sealed?	46%	57%	48	30
Garage walls sealed?	70%	82%	63	73
Tubs and showers sealed?	53%	75%	60	61
IC-rated light fixtures sealed?	81%	99%	104	75

[2] No above-code program was named in Phase I, and there were only two entries provided in Phase III – both EnergyStar.

[3] 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.

C.1.4 Duct & Piping Systems

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

Table C.8. Duct & Piping System Characteristics

Duct & Piping System Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Duct location in conditioned space (average percentage)				
Supply	17%	16%	103	152
Return	24%	17%	111	152
Ducts entirely in conditioned space (number and percentage)				
Supply	12 duct systems (17%)	6 duct systems (16%)		
Return	22 duct systems (24%)	12 duct systems (17%)		
Ducts in unconditioned space insulation (R-value)				
Supply	8.0	No observations	39	0
Return	7.8	8.0	35	1
Ducts in attic insulation (R-value)				
Supply	8.1	8.0	106	119
Return	7.9	7.7	98	114
Pipe insulation (R-value)			108	100
Average	R-2.4	R-2.8		
Range	R-0 to R-5	R-0 to R-5		
Building cavities used as supply ducts	97%	99%	116	99
Air ducts sealed	91%	97%	122	123
Air handlers sealed	82%	98%	113	122
Filter boxes sealed	77%	90%	106	118

C.1.5 HVAC Equipment

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

C.1.5.1 Heating

Table C.9. Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			129	124
Gas	36%	37%		
Electricity	64%	63%		
System Type			131	152
Furnace	37%	38%		
Heat Pump	60%	62%		
Electric Resistance	3%	1%		
Average System Capacity			122	NA*
Furnace	73,300 Btu/hr	NA*		
Heat Pump	43,200 Btu/hr	NA*		
Electric Resistance	59,500 Btu/hr	NA*		
Average System Efficiency			80	NA*
Furnace	83 AFUE	NA*		
Heat Pump	13 HSPF	NA*		

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

C.1.5.2 Cooling

Table C.10. Cooling Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			12	NA*
Central AC	31%	NA*		
Air Conditioning (unspec.)	2%	NA*		
Heat Pump	67%	NA*		
Average System Capacity			117	NA*
Central AC	41,300 Btu/hr	NA*		
Air Conditioning	51,000 Btu/hr	NA*		
Heat Pump	43,000 Btu/hr	NA*		
Average System Efficiency			72	NA*
Central AC	13 SEER	NA*		
Air Conditioning	13 SEER	NA*		
Heat Pump	13.4 SEER	NA*		

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

C.1.5.3 Water Heating

Table C.11. Water Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			110	104
Gas	54%	43%		
Electricity	46%	57%		
System Type			17	98
Storage	74%	89%		
Tankless	26%	11%		
Average System Capacity	52 gal	52 gal	65	66
Average System Efficiency			59	46
Electric Storage (non-heat pump)	EF 0.91	EF 0.89	25	25
Electric Storage (heat pump)	2.4	NA	1	0
Gas Storage	EF 0.69	EF 0.69	20	21
Gas Tankless	EF 0.86	NA	13	0

Table C.12. Water Heating System Storage Capacity Distribution

Capacity	< 50 gal	50-59 gal	60-69 gal	70-79 gal	80-89 gal	90+ gal
Phase I Percentage	5%	89%	2%	0%	0%	5%
Phase III Percentage	6%	89%	0%	0%	0%	5%

C.1.5.4 Ventilation

Table C.13. Ventilation Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			101	104
Exhaust Only	99%	87%		
AHU-Integrated	1%	13%		
Exhaust Fan Type			100	91
Dedicated Exhaust	0%	0%		
Bathroom Fan	100%	100%		

C.1.5.5 Other

Table C.14. Other Mechanical System Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Mechanical Manuals Provided	56%	97%	43	36

Appendix D

Energy Savings

Appendix D

Energy Savings

D.1 Measure-Level Savings

This appendix contains detailed measure-level annual savings results for both Phase I (Table D.1) and Phase III (Table D.2) for Alabama. Also included are multi-year (5-year, 10-year, and 30-year) aggregations of the annual results in Table D.3 and Table D.4. The multi-year savings reflect the same reductions and increases as the annual savings and are simply the annual savings multiplied by 15, 55, and 465 for 5-year, 10-year, and 30-year savings, respectively. For analytical details refer to Section 2.3.3 (Savings Analysis) or the methodology report (DOE 2018).

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

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)
Duct Tightness	312	5	1,517	9,506	14,420	395,063	2,272
Lighting	379	-1	1,146	9,506	10,891	385,451	2,408
Envelope Air Tightness	170	6	1,179	9,506	11,207	263,089	1,417
Exterior Wall Insulation	143	4	844	9,506	8,022	201,105	1,116
Window SHGC	59	-0.6	138	9,506	1,309	54,674	356
TOTAL	**1,064**	**12**	**4,823**	**9,506**	**45,849**	**1,299,382**	**7,569**

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

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)
Duct Tightness	255	4	1,240	9,506	11,785	323,238	1,874
Lighting	286	-1	864	9,506	8,203	290,649	1,847
Envelope Air Tightness	119	4	828	9,506	7,883	185,084	996
Exterior Wall Insulation	124	3	733	9,506	6,983	175,080	975
Window SHGC	5.19	-0.07	10	9,506	97	$4,534	261.14
TOTAL	**785**	**10**	**3,665**	**9,506**	**34,855**	**974,051**	**5,693**

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

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	216,300	793,100	6,705,300	5,925,945	21,728,465	183,704,295	34,080	124,960	1,056,480
Lighting	163,365	599,005	5,064,315	5,781,765	21,199,805	179,234,715	36,120	132,440	1,119,720
Envelope Air Tightness	168,105	616,385	5,211,255	3,946,335	14,469,895	122,336,385	21,255	77,935	658,905
Exterior Wall Insulation	120,330	441,210	3,730,230	3,016,575	11,060,775	93,513,825	16,740	61,380	518,940
Window SHGC	19,635	71,995	608,685	820,100	3,007,070	25,423,410	5,340	19,580	165,540
TOTAL	**687,735**	**2,521,695**	**21,319,785**	**19,490,730**	**71,466,010**	**604,212,630**	**113,535**	**416,295**	**3,519,585**

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

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	176,777	648,181	5,480,072	4,848,565	17,778,071	150,305,510	28,115	103,089	871,572
Lighting	123,052	451,191	3,814,617	4,359,739	15,985,710	135,151,913	27,709	101,601	858,988
Envelope Air Tightness	118,247	433,573	3,665,663	2,776,259	10,179,615	86,064,021	14,947	54,805	463,354
Exterior Wall Insulation	104,748	384,075	3,247,184	2,626,203	9,629,410	81,412,287	14,620	53,606	453,215
Window SHGC	1,455	5,335	45,105	68,010	249,370	2,108,310	3,915	14,355	121,365
TOTAL	**524,279**	**1,922,355**	**16,252,641**	**14,678,776**	**53,822,176**	**455,042,041**	**89,306**	**327,456**	**2,768,494**

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

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	39,523	144,919	1,225,228	$1,077,380	$3,950,394	$33,398,785	5,965	21,871	184,908
Lighting	40,313	147,814	1,249,698	$1,422,026	$5,214,095	$44,082,802	8,411	30,839	260,732
Envelope Air Tightness	49,858	182,812	1,545,592	$1,170,076	$4,290,280	$36,272,364	6,308	23,130	195,551
Exterior Wall Insulation	15,582	57,135	483,046	$390,372	$1,431,365	$12,101,538	2,120	7,774	65,725
Window SHGC	18,180	66,660	563,580	$752,090	$2,757,700	$23,315,100	1,425	5,225	44,175
TOTAL	**163,456**	**599,340**	**5,067,144**	**$4,811,954**	**$17,643,834**	**$149,170,589**	**24,229**	**88,839**	**751,091**

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

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

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

www.pnnl.gov