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North Carolina Residential Energy Code Field Study: Final Report

September 2022

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U.S. DEPARTMENT OF ENERGY

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

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

A research project in the State of North Carolina 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 North Carolina field study, including a summary of key trends observed in the field, their impact on energy efficiency, and whether the selected education and training activities resulted in a measurable change in statewide energy use. Public and private entities—state government agencies, utilities, and others—can also use this information to justify and catalyze investments in workforce education, training and related energy efficiency programs.

Background

The baseline field study (Phase I) was initiated in January 2015 and continued through September 2015. During this period, research teams visited 249 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 North Carolina homes, and indicated over $2 million in potential annual savings to homeowners in the state that could result from increased code compliance (Table ES.2).

Starting in March 2016 and continuing through July 2017, members of the North Carolina field study team conducted targeted education and training activities (Phase II). Those activities included circuit rider assistance[1], in-person trainings to a wide variety of stakeholders in the new construction industry, an energy code hotline, direct mail campaign, and online videos with other educational resources. 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 134 homes across the state between August 2017 and December 2017. The results of this effort are presented in Table ES.1 and discussed further in Section 3.0.

Methodology

The project team was led by Appalachian State University. 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[2]. 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] A *circuit rider* is an individual with subject matter expertise who mobilizes to serve multiple jurisdictions across a given geographic area (e.g., providing insight, expertise and training on compliance best practices).
[2] 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.

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.

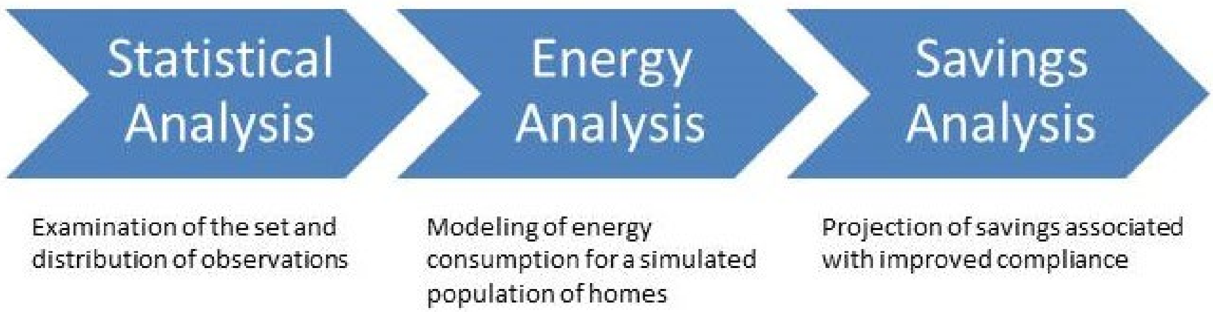

Figure ES.1. Stages of Analysis Applied in the Study

Results

As shown in Table ES.1, the Phase I analysis indicated homes used about 3.5 percent less energy than would be expected relative to homes built to the minimum prescriptive requirements of the current state code. The average energy use increased between Phases I and III rather than decreased.

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

Prescriptive EUI[1]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
23.79	22.96	-3.5%	23.26	-2.2%	+1.3%

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

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

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**
Lighting	$520,839	$298,634	-$222,205	-42.7%
Exterior Wall Insulation	$390,827	$326,455	-$64,372	-16.5%
Duct Tightness	$334,527	$677,227	+$342,700	+102.4%
Ceiling Insulation	$503,364	$435,289	-$68,075	-13.5%
Envelope Air Tightness	$211,315	$561,908	+$350,593	+165.9%
Foundation Insulation	$65,086	$68,531	+$3,445	+5.3%
TOTAL	**$2,025,958**	**$2,368,044**	**-$342,086**	**-16.9%**

Significant reductions in lighting savings potential occurred, and exterior wall and ceiling insulation are trending in the right direction. However, the overall results are not trending in the right direction. Opportunities for improvement still exist.

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

Acknowledgments

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

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

- Janet Miller, Chuck Perry, and Jeff Tiller, *Appalachian State University*
- Joseph Crocker, *Appalachian State University*
- Grace Plummer and Sharon Yates, *Appalachian State University*
- Chase Edge and Jakob Sjostrand, *Appalachian State University*
- Dale Akins, *The Market Edge, LLC*
- John Kidda, *reNew Home*
- Mark Jabaley, *Above and Beyond Energy*
- David Watts, *MSA Marketing*

Appalachian State University Energy Center

The Appalachian Energy Center is housed within the Research Institute for the Environment, Energy, and Economy at Appalachian State University. The mission of the Center is to conduct applied research and to provide services and education in support of the development and deployment of clean energy technologies, policies, and economies. One of the Center's initiatives is the North Carolina Energy Efficiency Alliance (NCEEA) which was established in 2010 as a state-funded non-profit organization with the goal of supporting energy efficient and third party certified construction in NC. The NCEEA is dedicated to educating all the various stakeholders in the home building industry about the benefits of constructing energy efficient homes and buildings. More information is available at https://energy.appstate.edu and http://ncenergystar.org.

The Market Edge, LLC

The Market Edge is a specialized information reporting service that provides leads to building material suppliers, subcontractors, financial institutions, governmental agencies, and other companies that provide goods and services to the residential and commercial construction industry. More information is available at http://www.themarketedge.com.

reNew Home

reNew Home strives to improve existing homes and small commercial buildings by using building science methodology to carry out renovation projects, placing emphasis on occupant safety, energy conservation, sustainable materials, and livability. reNew Home served as a site auditor for the field study. More information is available at http://www.renewhomeinc.com.

Above and Beyond Energy

Above and Beyond Energy was formed by Mark and Marianna Jabaley in 2007, with one mission: to help professionals and laymen alike, to build only the highest performing homes in the Coastal Carolinas. They have built an award winning company that serves clients all across North Carolina. Above and Beyond Energy served as a site auditor for the field study as well as assisted the project team in the Phase 2 training. See http://aboveandbeyondenergy.com for more information.

MSA Marketing

MSA is a full-service marketing firm located in Raleigh, NC. Founded in 1991, MSA is a small, dynamic and growing team with big agency capabilities. They offer a wide range of services for a diverse mix of clients, with a drive to help them achieve results. MSA assisted the project team in the creation of Energy Code videos used in Phase 2 of the project. Visit http://thinkmsa.com for more information.

Acronyms and Abbreviations

AC	air conditioning
ACH	air changes per hour
AFUE	annual fuel utilization efficiency
AHU	air handling unit
AIA	American Institute of Architects
ASU	Appalachian State University
Btu	British thermal unit
cfm	cubic feet per minute
CZ	climate zone
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EUI	energy use intensity
FOA	funding opportunity announcement
HSPF	heating season performance factor
ICC	International Code Council
IECC	International Energy Conservation Code
kBtu	thousand British thermal units
MMBtu	million British thermal units
NA	not applicable
NC	North Carolina
NCBCC	North Carolina Building Code Council
NCECC	North Carolina Energy Efficient Code
PNNL	Pacific Northwest National Laboratory
SHGC	solar heat gain coefficient

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1.0 Introduction

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

The baseline field study (Phase I) was initiated in January 2015 and continued through September 2015. During this period, research teams visited 249 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 North Carolina homes, and indicated over $2 million in potential annual savings to homeowners in the state that could result from increased code compliance.

Starting in March 2016 and continuing through July 2017, members of the North Carolina field study team conducted targeted education and training activities (Phase II). Those activities included in-person trainings, direct assistance to code officials, development of guides and videos, and direct mail. 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 134 homes across the state between August 2017 and December 2017. The results of this effort are presented in Section 3.0. At the time of the study, the 2012 North Carolina Energy Conservation Code was in effect, which was an amended version of a draft of the 2012 International Energy Conservation Code (IECC). The study methodology, data analysis and resulting findings are presented throughout this report.

1.1 Background

The data collected and analyzed for this report was in response to the U.S. Department of Energy (DOE) Funding Opportunity Announcement (FOA)[1] with the goal of determining whether an investment in education, training, and outreach programs can produce a significant, measurable change in single-family residential building code energy use. Participating states:

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

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

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

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

Energy codes for residential buildings have advanced significantly in recent years, with today's model codes approximately 30% more efficient than codes adopted by the majority of U.S. states. [2,3] Hence, the importance of ensuring code-intended energy savings, so that homeowners realize the benefits of improved codes—something which happens only through high levels of compliance. More information on the original FOA and overall goals of the study is available on the DOE Building Energy Codes Program website.[4]

1.2 Project Team

The North Carolina project and field data collection were led by Appalachian State University (ASU). The Pacific Northwest National Laboratory (PNNL) defined the methodology, conducted data analysis, and provided technical assistance to the project team. Funding and overall program direction was provided by the DOE Building Energy Codes Program as part of a broader initiative being conducted across several U.S. states. More information on the organizations comprising the project team is included in the Acknowledgements section of this report.

1.3 Stakeholder Interests

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

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

A description of the stakeholders who participated in the project 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

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

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 North Carolina 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 North Carolina study, including sampling, data collection, and resulting data analysis. More information on the DOE data collection and analysis methodology is published separately from this report (DOE 2018) and is available on the DOE Building Energy Codes Program website.[3]

2.2 State Study

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

2.2.1 Sampling

PNNL developed statewide sampling plans statistically representative of recent construction activity within the state. The samples were apportioned to jurisdictions across the state in proportion to their average level of construction compared to the overall construction activity statewide. This approach is a proportional random sample, which PNNL based on the average of the three most recent years of Census Bureau permit data[4]. The sampling plan specified the number of key item observations required in each selected county (totaling 63 of each key item across the entire state). North Carolina comprises multiple climate zones (CZ 3, 4 and 5, but only CZ 3 and 4 were selected in the random sample in Phase I[5]). In Phase III, several CZ 5 homes were included.

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 statewide sample plans, the project team began acquiring permit data. The primary source of data was from The Market Edge, a specialized information reporting service that provided substantial data on new housing starts in most of the counties selected for sampling. In counties where data was not available from The Market Edge, the local building departments were contacted to identify homes currently in the permitting process. Code officials responded by providing lists of homes at various stages of construction within their jurisdiction. 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.

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

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

[5] Due to minimal construction activity in CZ 5

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 2012 North Carolina Energy Conservation Code (an amended version of a draft of the 2012 IECC). The final data collection form is available in spreadsheet format on the DOE Building Energy Codes Program website.[6] The form included all energy code requirements (i.e., not just the eight key items), as well as additional items required under the prescribed methodology. For example, the field teams were required to conduct a blower door test and duct tightness test on every home where such tests could be conducted, using RESNET[7] protocols.

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

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

2.2.2.2 Data Management and Availability

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

2.3 Data Analysis

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

1. **Statistical Analysis:** Examination of the data set and distribution of observations for individual measures
2. **Energy Analysis:** Modeling of energy consumption for a simulated population of homes

[6] Available at https://www.energycodes.gov/residential-energy-code-field-studies. and based on the forms typically used by the RES*check* compliance software.
[7] See https://www.resnet.us/wp-content/RESNET-Mortgage-Industry-National-HERS-Standards_3-8-17.pdf
[8] Available at https://www.energycodes.gov/residential-energy-code-field-studies.

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

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

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

2.3.1 Statistical Analysis

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

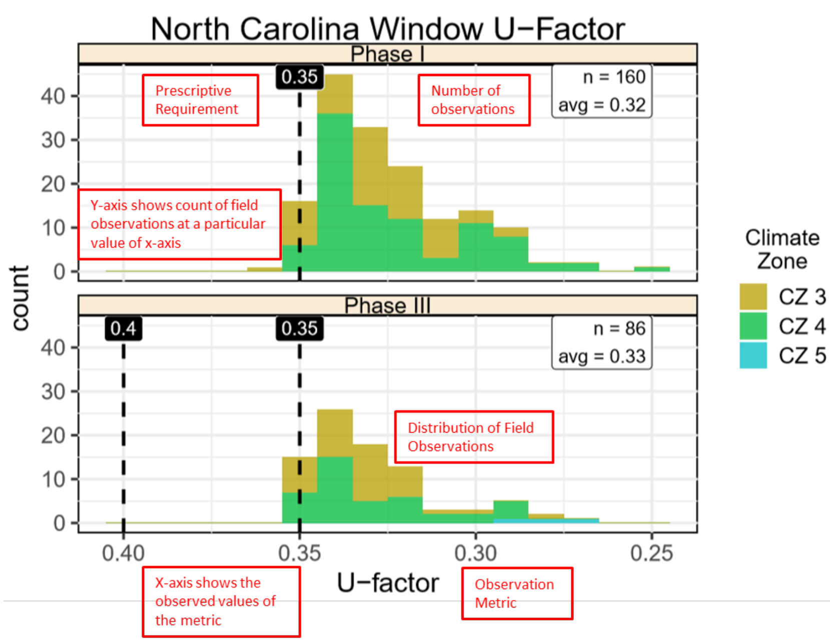

Figure 2.1. Sample Graph

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

2.3.2 Energy Analysis

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

Energy simulation was then conducted using the EnergyPlus™ software.[9] Each of the 1,500 models was run multiple times, to represent each combination of heating systems and foundation types commonly found in the state. This resulted in upwards of 30,000 simulation runs for each climate zone within the state. An EUI was calculated for each simulation run and these results were then weighted by the frequency with which the heating system/foundation type combinations were observed in the field data. Average EUI was calculated based on regulated end uses (heating, cooling, lighting and domestic hot water) for two sets of homes—one *as-built* set based on the data collected in the field, and a second *code-minimum* set (i.e., exactly meeting minimum code requirements). Comparing these values shows whether the population of newly constructed homes in the state is using more or less energy than would be expected based on minimum code requirements. In the energy analysis, the presence of both above code and below code items is included and therefore reflected in the statewide EUI.

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

2.3.3 Savings Analysis

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

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

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

[11] "Significant" was defined as 15% or more of the observed values not meeting the associated code requirement. Only the items above this threshold were analyzed. However, if a measure met the 15% threshold in Phase I but not in Phase III, it was still included in the measure-level savings for Phase III regardless of the worse-than-code percentage so as not to potentially overstate savings by ignoring the reduced, but not necessarily zero, measure-level savings in Phase III.

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

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

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

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

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

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 North Carolina, specific Phase II activities included:

- In total, 71 presentations were made to 1700 key stakeholders.
- Direct assistance to code officials: In-office sessions (1-3 hour programs) were held at 22 locations for a total of 436 code officials. In addition, three sessions were presented at code official annual meetings for 144 code officials.
- Training at meetings and conferences:
  - Home builders: 18 training sessions (1-2 hour programs) were held at home builder association meetings to a total of 317 attendees, and an information book and training presentations were provided at three annual home building conferences for 54 attendees.
  - Insulation contractors: 10 training sessions for 115 attendees focused on building science, manufacturers’ installation instructions, and code requirements (sponsored by NAIMA).
  - Home energy raters: 3 training sessions for 87 attendees.

- State home inspectors: 1 training session for 125 attendees.
- State energy conference: 3 training sessions for 147 attendees.

- Project website, a part of ncenergystar.org, was created and averaged approximately 1,000 hits per month.
- Energy code compliance guides: 1- and 2-page guides covering the key items (General Residential, Knee Wall, Slab Insulation, HVAC and Duct Sealing, and High-Efficacy Lighting), available at www.ncenergystar.org.
- Videos:
  - Energy Center Live – Series of five videos with sports commentator theme and humor covering code target areas: (insulation slab-on-grade floor systems, knee walls, high-efficacy lighting, duct sealing and testing, and air sealing) on website and https://www.youtube.com/user/NCEEA
  - Energy Code Essentials – This was used as part of an online promotion for code inspectors and home builders – watch a five-minute video, answer five questions, and receive a $5 Starbucks card
  - Six "how-to" videos were created on these topics: insulating a monolithic slab foundation, insulating a stem wall foundation, framed knee wall insulation, truss knee wall insulation, insulating around outlets, and chase air sealing.
- Training video animations: A series of eight SketchUp animations depicting proper assemblies related to common compliance issues. Available at https://www.youtube.com/user/NCEEA.
- Direct mail and email: infographic type postcards highlighting problem areas found in the field were mailed to 110 major HVAC contractors, 50 major insulation contractors, and 1,300 code officials. In addition, a letter urging improved compliance was mailed to the 1,300 code officials, and targeted emails were send using the North Carolina Electrical Contractor list of 10,000 regarding lighting. A newsletter was emailed to 3,000 people quarterly.
- Other: In addition, a photo library showing compliant and non-compliant practices and energy-efficient details available to download in DWG and PDF formats, available at www.ncenergystar.org.

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

The two main foundation types observed in Phase I were slabs on grade and floors over vented crawlspaces or unheated basements. In addition, there were five basement wall observations for heated basements in Phase I and four in Phase III but due to that small number of observations, graphics are only provided for slabs and floors. In Phase III, unvented crawlspaces were also observed, but no observations of crawlspace wall insulation were recorded, so no crawlspace wall graphics are included.

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

3.1.1.1 Envelope Tightness

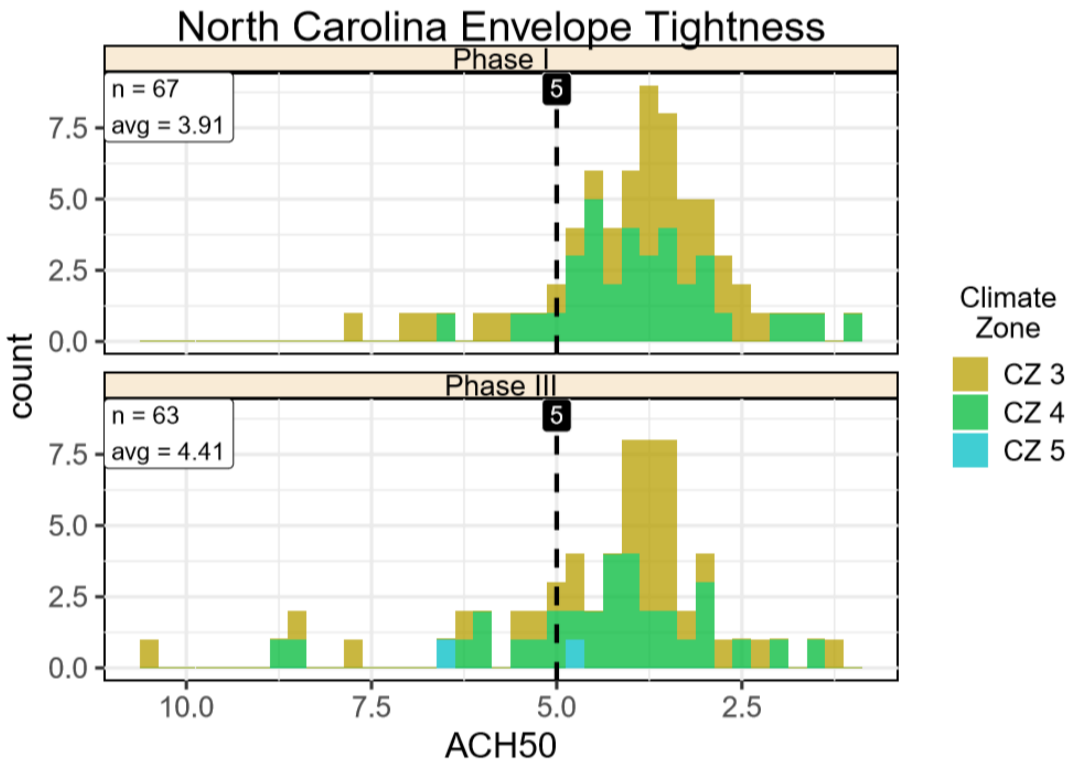

Figure 3.1. Comparison of Phase I and Phase III Envelope Tightness for North Carolina

Table 3.1. North Carolina Envelope Tightness in Phase I and Phase III

Envelope Tightness (ACH50)	Phase I			Phase III			
	CZ3	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Observations							
Number	32	35	67	30	31	2	63
Range	7.79 to 2.36	6.5 to 1.0	7.79 to 1.0	10.5 to 1.2	8.66 to 1.6	6.6 to 4.7	10.5 to 1.2
Average	4.0	3.8	3.9	4.3	4.4	5.7	4.4
Requirement Compliance Rate	27 of 32 (84%)	32 of 35 (91%)	59 of 67 (88%)	24 of 30 (80%)	23 of 31 (74%)	1 of 2 (50%)	48 of 63 (76%)

- **Interpretations:**
  - Although the majority of the observations met or exceeded the prescriptive code requirement and envelope air tightness was a focus of Phase II education and training activities, the compliance rate decreased from Phase I to Phase III. Opportunity for further savings exists.

3.1.1.2 Window SHGC

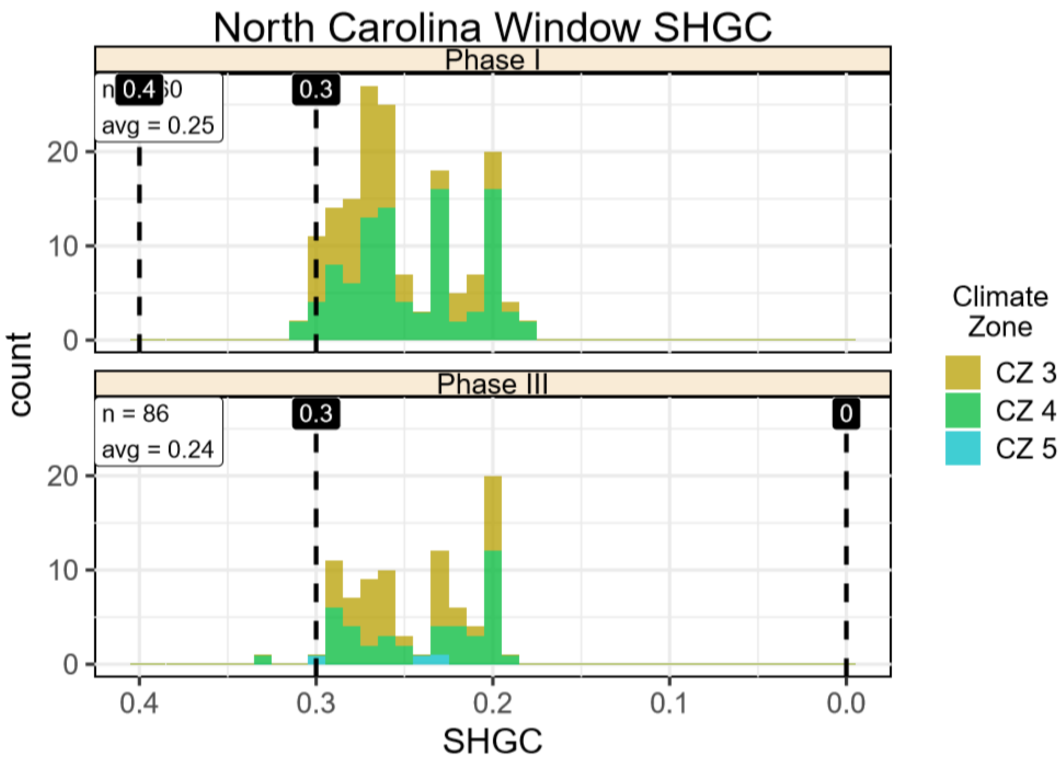

Figure 3.2. Comparison of Phase I and Phase III Window SHGC for North Carolina

Table 3.2. North Carolina Window SHGC in Phase I and Phase III

Window SHGC	Phase I			Phase III			
	CZ3	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Observations							
Number	64	96	160	42	41	3	86
Range	0.30 to 0.19	0.31 to 0.18	0.31 to 0.18	0.29 to 0.20	0.33 to 0.19	0.3 to 0.23	0.33 to 0.19
Average	0.26	0.25	0.25	0.25	0.24	0.24	0.24
Compliance Rate	64 of 64 (100%)	94 of 96 (98%)	158 of 160 (99%)	42 of 42 (100%)	40 of 41 (98%)	3 of 3 (100%)	85 of 86 (99%)

- **Interpretations:**
  - SHGC values were fully compliant in CZ3 in both Phase I and Phase III, and overall, only three observations did not meet the prescriptive requirement.
  - The vast majority of the observations were in the 0.20 to 0.30 SHGC range in both phases.

3.1.1.3 Window U-Factor

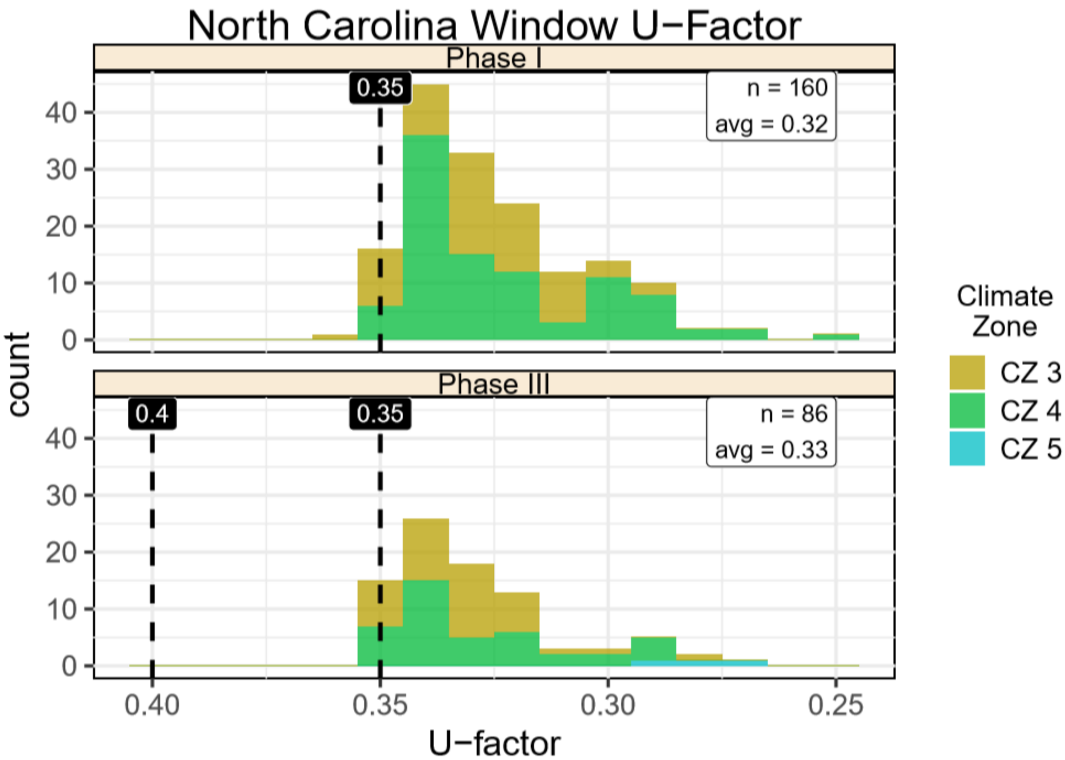

Figure 3.3. Comparison of Phase I and Phase III Window U-Factors for North Carolina

Table 3.3. North Carolina Window U-Factor in Phase I and Phase III

Window U-Factor	Phase I			Phase III			
	CZ3	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Observations							
Number	64	96	160	42	41	3	86
Range	0.36 to 0.29	0.35 to 0.25	0.36 to 0.25	0.35 to 0.28	0.35 to 0.29	0.29 to 0.27	0.35 to 0.28
Average	0.33	0.32	0.32	0.33	0.33	0.28	0.33
Compliance Rate	63 of 64 (98%)	96 of 96 (100%)	159 of 160 (99%)	42 of 42 (100%)	41 of 41 (100%)	3 of 3 (100%)	86 of 86 (100%)

- **Interpretations:**
  - All but one observed fenestration product in the state met or exceeded the U-factor requirements in Phase I, and all met or exceeded in Phase III.
  - This represents one of the most significant findings of the field study.
  - Window U-factor requirements appear to have been implemented with a high rate of success across the state.

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.

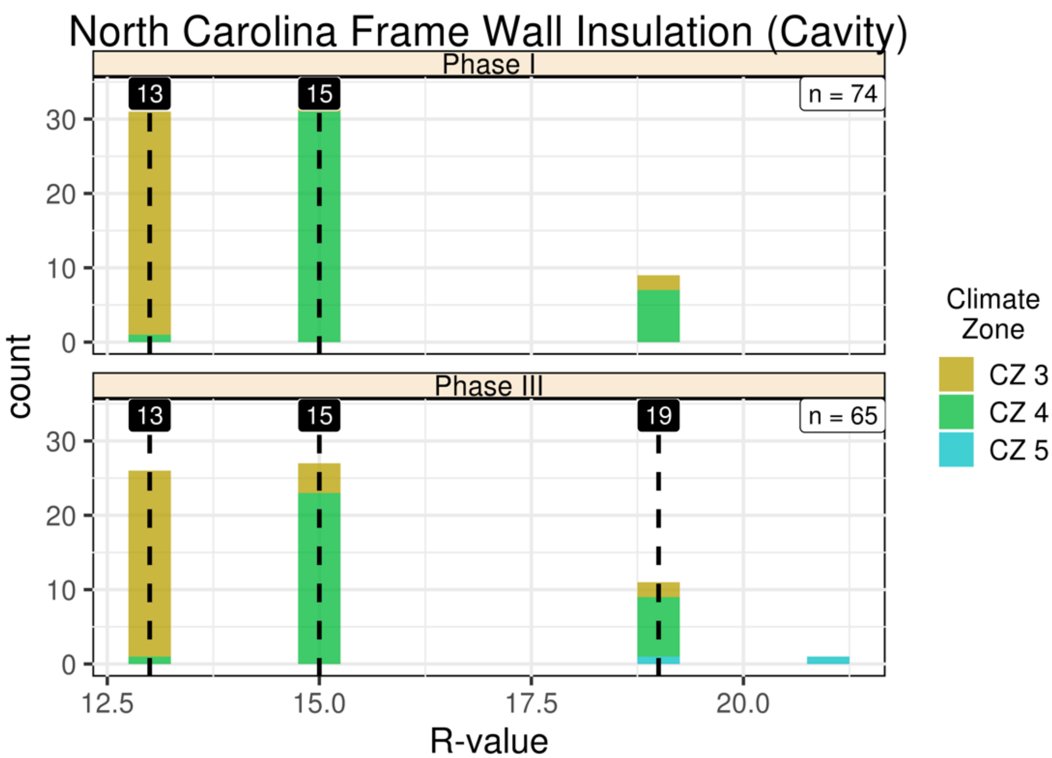

Figure 3.4. Comparison of Phase I and Phase III Wall R-Values for North Carolina

At the start of the overall project, IIQ was noted as a particular concern among project teams and stakeholders, as it plays an important role in the energy performance of envelope assemblies. IIQ was therefore collected by the field teams whenever possible and applied as a *modifier* in the analyses for applicable key items (i.e., wall insulation, ceiling insulation, and foundation insulation). Teams followed the RESNET[2] assessment protocol for cavity insulation which has three grades; Grade I being the best quality installation and Grade III being the worst.

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

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

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

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	31 / 36	38 / 26	0 / 3	**69 / 65**
Above Grade Percentages	45% / 55%	55% / 40%	0% / 5%	**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.

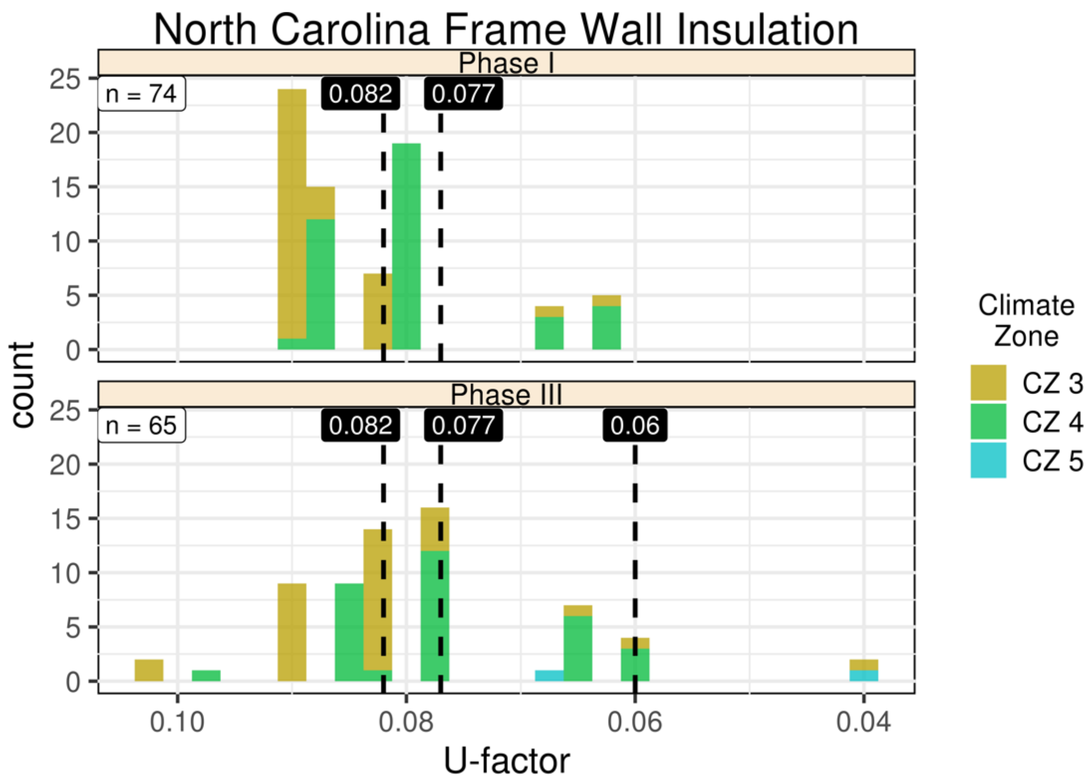

Figure 3.5. Comparison of Phase I and Phase III Wall U-Factors for North Carolina

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

	Phase I			Phase III			
Wall U	**CZ3**	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	0.082	0.077	0.082 in CZ3 and 0.077 in CZ4	0.082	0.077	0.060	0.082 in CZ3, and 0.077 in CZ4, and 0.060 in CZ5
Observations							
Number	35	39	74	31	32	2	65
Range	0.092 to 0.062	0.092 to 0.062	0.092 to 0.062	0.103 to 0.040	0.099 to 0.059	0.066 to 0.041	0.103 to 0.040
Average	0.088	0.079	0.083	0.083	0.076	0.054	0.079

Wall U	Phase I CZ3	Phase I CZ4	Phase I Statewide	Phase III CZ3	Phase III CZ4	Phase III CZ5	Phase III Statewide
Compliance Rate	2 of 35 (6%)	7 of 39 (18%)	9 of 74 (12%)	20 of 31 (65%)	21 of 32 (66%)	1 of 2 (50%)	42 of 65 (65%)

- **Interpretations:**
  - The cavity insulation requirement is achieved at a high rate—all of the observations in CZ3 and all but one observation in CZ4 (in both Phase I and Phase III), and all observations in CZ5 meet or exceed the prescriptive code requirement for wall cavity insulation (based on labeled R-value).
  - From an assembly perspective, a majority of observations (55%) in Phase I had Grade II or Grade III IIQ. Grade I observations in Phase III increased, but there is still a significant number of Grade II and Grade III observations.
  - While the cavity insulation requirement appears to be achieved successfully (R-value), the overall assembly performance (U-factor) is a continued savings opportunity.

3.1.1.5 Ceiling Insulation

Figure 3.6 represents the observed R-values for North Carolina ceilings.

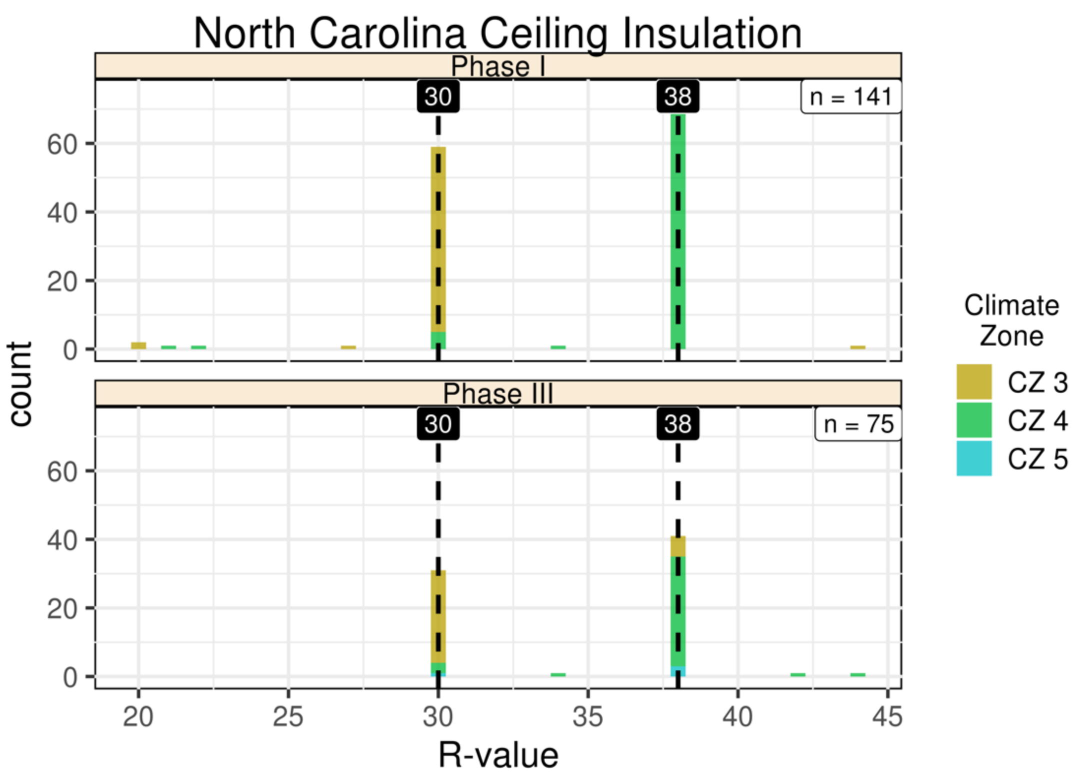

Figure 3.6. Comparison of Phase I and Phase III Ceiling R-Values for North Carolina

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

	Phase I			Phase III			
Ceiling R	**CZ3**	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	30.0	38.0	30.0 in CZ3 and 38.0 in CZ4	30.0	38	38	30.0 in CZ3 and 38.0 in CZ4/5
Observations							
Number	62	79	141	33	38	4	75
Range	20 to 44	21 to 38	20 to 44	30 to 38	30 to 44	30 to 38	30 to 44
Average	30.4	37.0	34.1	31	38	36	35
Compliance Rate	59 of 62 (95%)	71 of 79 (90%)	130 of 141 (92%)	33 of 33 (100%)	34 of 38 (89%)	3 of 4 (75%)	70 of 75 (93%)

Table 3.7 shows the number and percentage of IIQ observations by grade for roof cavity insulation for Phase I and Phase III. The table illustrates that roof cavity IIQ improved from Phase I to Phase III, with 75% of the Phase III observations being Grade I.

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

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	98 / 55	36 / 14	5 / 4	**139 / 73**
Roof Cavity Percentages	70% / 75%	26% / 19%	4% / 6%	**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.

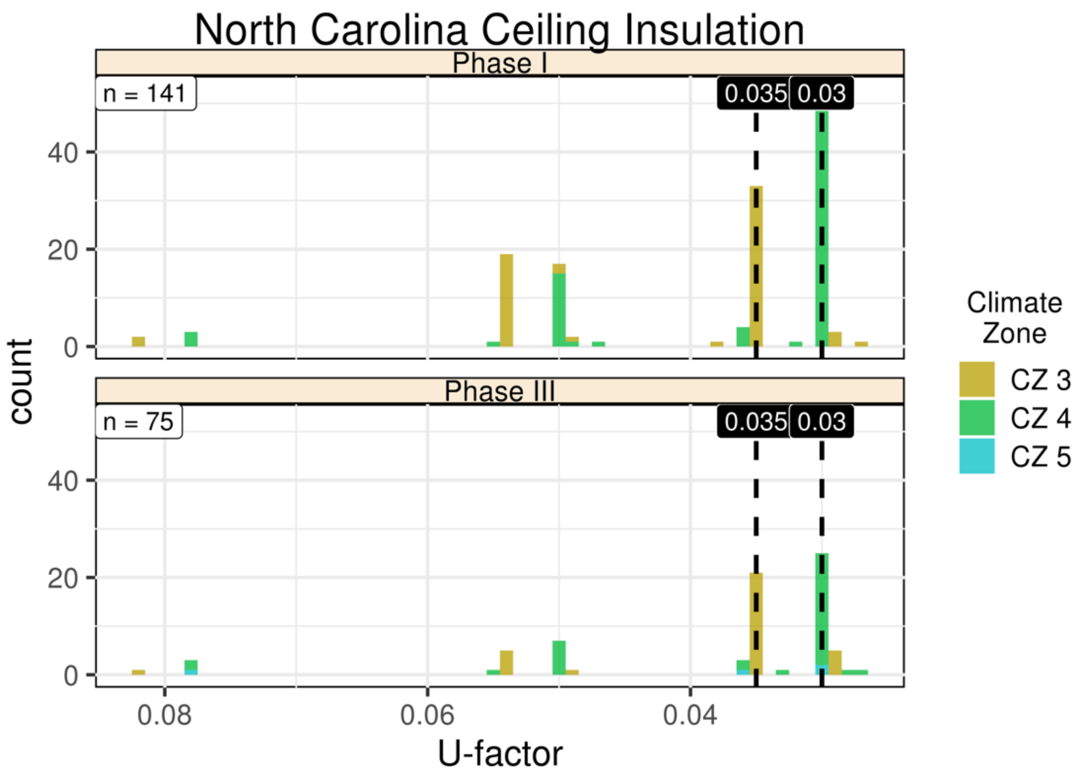

Figure 3.7. Comparison of Phase I and Phase III Ceiling R-Values for North Carolina

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

	Phase I			**Phase III**			
Ceiling U	**CZ3**	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	0.035	0.030	0.035 in CZ3 and 0.030 in CZ4	0.035	0.030	0.030	0.035 in CZ3 and 0.030 in CZ4 and CZ5
Observations							
Number	62	79	141	33	38	4	75
Range	0.082 to 0.027	0.078 to 0.030	0.082 to 0.027	0.082 to 0.029	0.078 to 0.027	0.078 to 0.030	0.082 to 0.027
Average	0.043	0.037	0.039	0.039	0.037	0.044	0.038
Compliance Rate	37 of 62 (60%)	53 of 79 (67%)	90 of 141 (64%)	26 of 33 (79%)	25 of 38 (66%)	2 of 4 (50%)	53 of 75 (71%)

- **Interpretations:**
  - Nearly all of the observations in both Phases I and III met the R-value code requirement exactly.
  - From an assembly perspective, Grade I observations in Phase III increased, but there is still a significant number of Grade II and Grade III observations.
  - While the cavity insulation requirement appears to be achieved successfully (R-value), the overall assembly performance (U-factor) is a continued savings opportunity.

3.1.1.6 Lighting

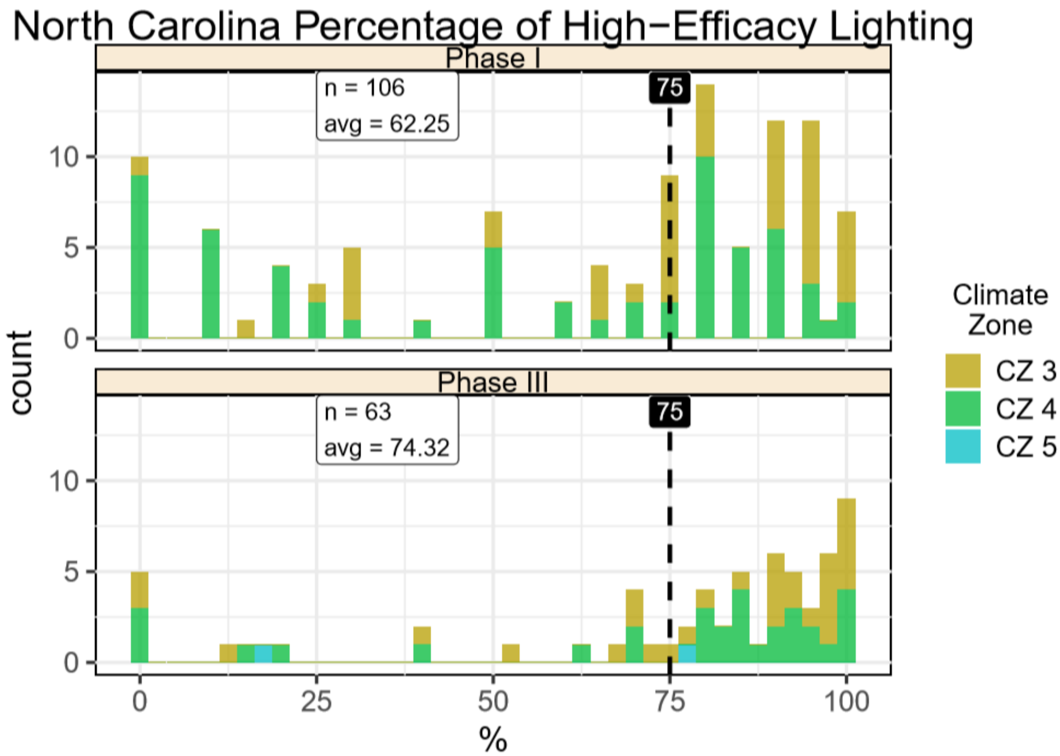

Figure 3.8. Comparison of Phase I and Phase III High-Efficacy Lighting Percentages for North Carolina

Table 3.9. North Carolina High-efficacy Lighting in Phase I and Phase III

	Phase I			Phase III			
Lighting	**CZ3**	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	75	75	75	75	75	75	75
Observations							
Number	44	62	106	30	31	2	63
Range	0 to 100	0 to 100	0 to 100	0 to 100	0 to 100	18 to 78	0 to 100
Average	74.2	53.8	62.3	77.6	72.9	48.0	74.3
Compliance Rate	31 of 44 (70%)	29 of 62 (47%)	60 of 106 (57%)	21 of 30 (70%)	22 of 31 (71%)	1 of 2 (50%)	44 of 63 (70%)

- **Interpretations:**
  - A little more than half of the observations met the requirement in Phase I; a much lower number than expected based on the current code. Lighting was a focus of Phase II education and training activities.
  - Lighting improved in Phase III but remains a continued savings opportunity.

3.1.1.7 Foundation Assemblies

There were two predominant foundation types observed in North Carolina: slabs and floors. Floors include those observations where floor insulation is installed, such as over vented crawlspaces and unconditioned basements. Two graphs are shown for each climate zone for floors, insulation (R-value) and binned assembly (U-factor). The R-value graph shows the insulation R-values observed. The binned U-factor graph indicates the U-factor of the assembly, including cavity insulation, continuous insulation, and framing, with consideration of insulation installation quality, as observed in the field. The U-factors are binned to reduce the number of bars in the chart since individual U-factor observations may be only slightly different. For slabs, only an R-value graph is shown.

In addition, there were five basement wall observations for heated basements in Phase I and four in Phase III but due to that small number of observations, graphics are only provided for slabs and floors. In Phase III, unvented crawlspaces were also observed, but no observations of crawlspace wall insulation were recorded, so no crawlspace wall graphics are included.

While initially combined into a single key item (i.e., foundation assemblies[3]), the variety of observed foundation types is disaggregated in this section, as described above. This approach helps to portray the combinations of cavity and continuous insulation employed across each foundation type, which was anticipated to be of value for energy code training programs. From a savings perspective, results are calculated for both the aggregated perspective individual foundation types (presented later in Section 3.3), however; only the aggregated observations should be considered statistically representative at the statewide level.

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

Slabs

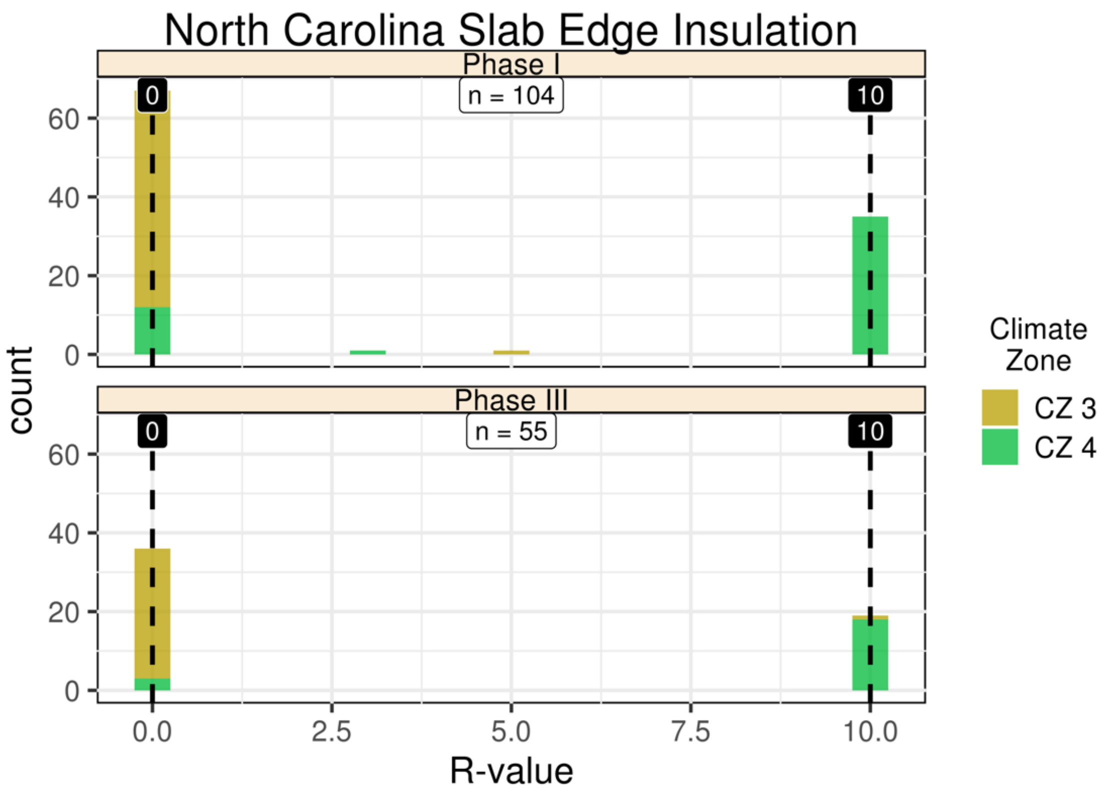

Figure 3.9. Comparison of Phase I and Phase III Slab R-Values for North Carolina

Table 3.10. North Carolina Slab R-Values in Phase I and Phase III[4]

	Phase I			Phase III		
Slab R	**CZ3**	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**Statewide**
Requirement	0*	10.0	10.0	0*	10.0	10.0
Observations						
Number	56	48	104	34	21	55
Range	0.0 to 5.0	0.0 to 10.0	0.0 to 10.0	0.0 to 10.0	0.0 to 10.0	0.0 to 10.0
Average	0.09	7.4	3.4	0.29	8.6	3.45
Compliance Rate	56 of 56 (100%)	35 of 48 (73%)	91 of 104 (88%)	34 of 34 (100%)	18 of 21 (86%)	52 of 55 (95%)

*The NC Energy Code lists the requirement in CZ3 as R-0.

- **Interpretations**
  - Slab edge insulation improved from 73% to 86% of the observations in CZ4 meeting the requirement from Phase I to Phase III.
  - The project team noted that slab insulation quality was not an observation on the field study input form; however, field observations and supporting photos in Phase I revealed that in a number of

[4] There were no slab insulation observations in CZ5.

cases, slab insulation was installed poorly. Phase II education and training efforts highlighted key steps for quality installation.

Floors

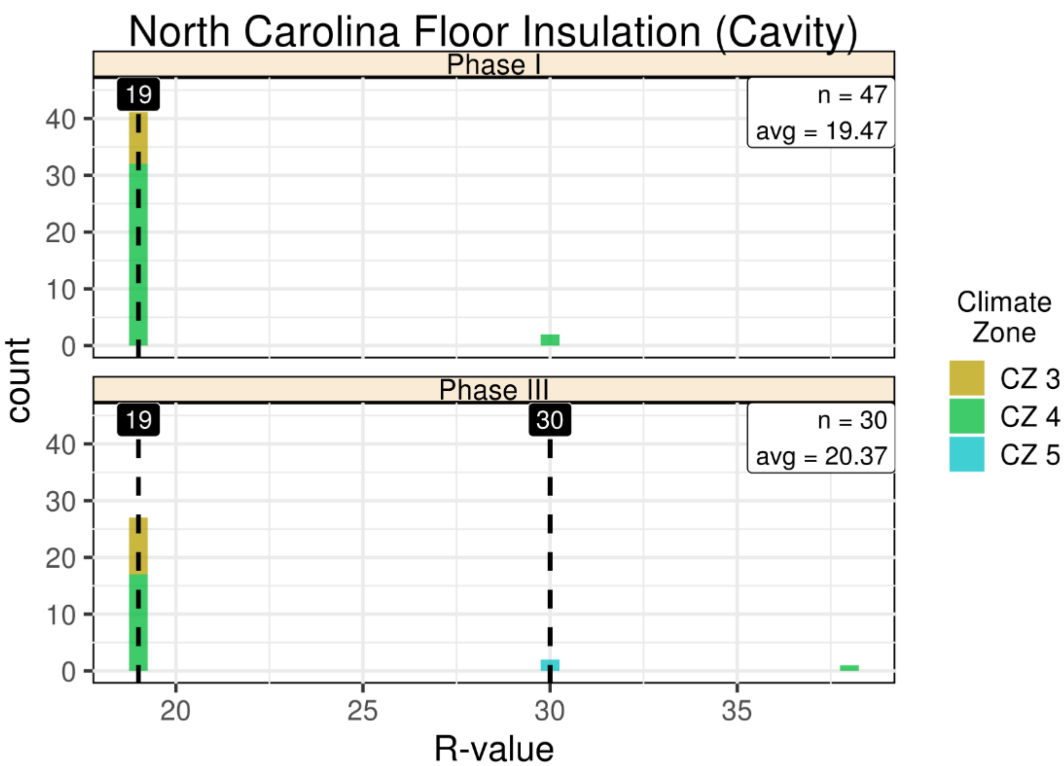

Figure 3.10. Comparison of Phase I and Phase III Floor R-Values for North Carolina

Table 3.11 shows the number and percentage of IIQ observations by grade for floor insulation for Phase I and Phase III. The table illustrates that floor IIQ improved from Phase I to Phase III, although there were more Grade III observations. 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 3.11.

Table 3.11. Floor IIQ Comparison between Phase I and Phase III for North Carolina

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Floor Observations	42 / 20	35 / 4	1 / 7	**78 / 31**
Floor Percentages	54% / 65%	45% / 13%	1% / 22%	**100% / 100%**

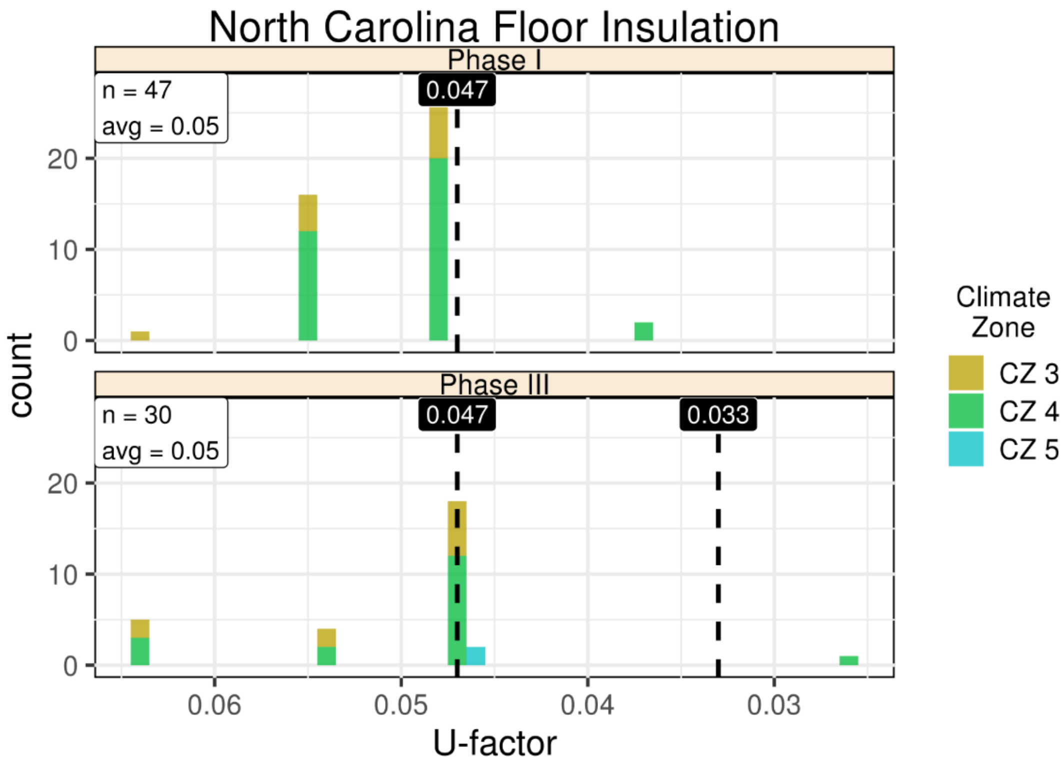

Figure 3.11. Comparison of Phase I and Phase III Floor U-Factors for North Carolina

Table 3.12. North Carolina Floor U-Factors in Phase I and Phase III

	Phase I			Phase III			
Floor U	**CZ3**	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	0.047	0.047	0.047	0.047	0.047	0.033	0.047 in CZ3 and CZ4, 0.033 in CZ5
Observations							
Number	13	34	47	10	18	2	30
Range	0.064 to 0.047	0.055 to 0.037	0.064 to 0.037	0.064 to 0.047	0.064 to 0.026	0.046 to 0.046	0.064 to 0.026
Average	0.051	0.050	0.050	0.052	0.049	0.046	0.050
Rate	8 of 13 (62%)	20 of 34 (59%)	28 of 47 (60%)	6 of 10 (60%)	13 of 18 (72%)	0 of 2 (0%)	19 of 30 (63%)

- **Interpretations**
  - The cavity insulation requirement is achieved at a high rate in both phases (based on labeled R-value).
  - From an assembly perspective, the overall U-factor exhibits room for improvement as nearly half of the observations in Phase I had IIQ levels of Grade II/III. IIQ improved in Phase III, with only 35% in Grade II/III. Although IIQ improved overall, continued savings opportunity exists.

3.1.1.8 Duct Tightness

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

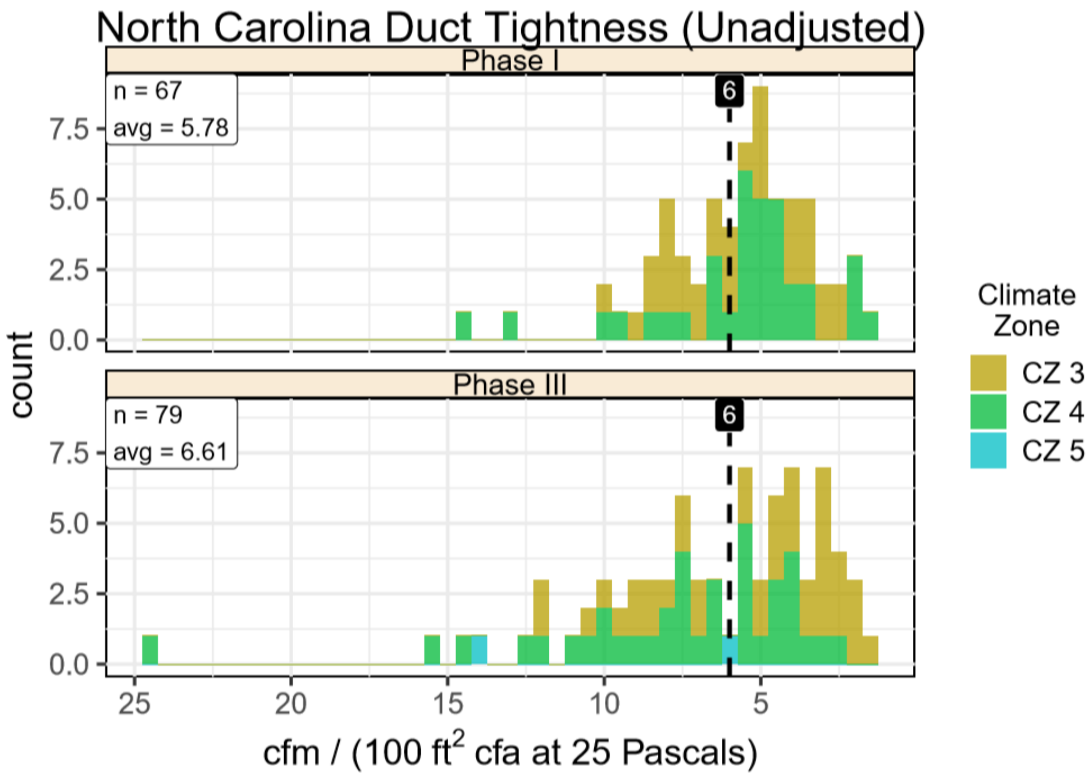

Figure 3.12. Comparison of Phase I and Phase III Duct Tightness Values for North Carolina

Table 3.13. North Carolina Duct Tightness Values in Phase I and Phase III (unadjusted)

	Phase I			Phase III			
Duct Tightness	**CZ3**	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	6.0	6.0	6.0	6	6	6	6
Observations							
Number	32	35	67	39	38	2	79
Range	9.9 to 2.49	14.4 to 1.70	14.4 to 1.70	11.9 to 1.50	24.5 to 2.60	13.8 to 6.2	24.5 to 1.5
Average	5.8	5.3	5.8	5.4	7.6	10.0	6.6
Compliance Rate	18 of 32 (56%)	25 of 35 (71%)	43 of 67 (64%)	25 of 39 (64%)	16 of 38 (42%)	0 of 2 (0%)	41 of 79 (52%)

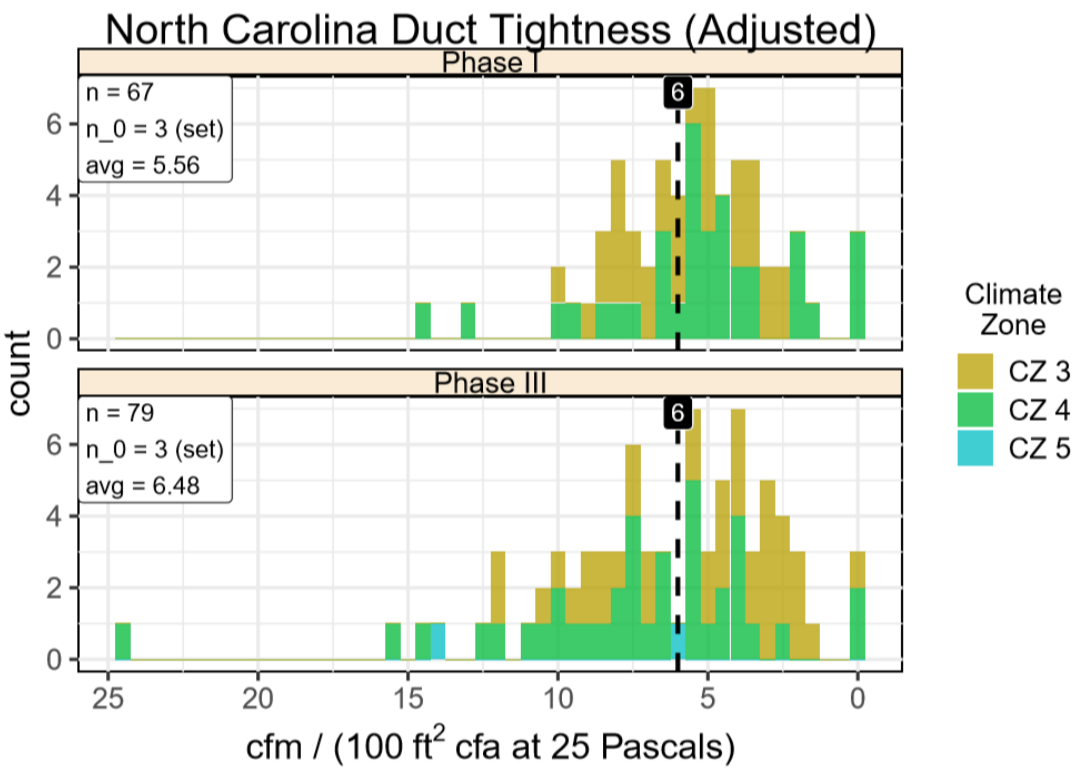

Figure 3.13. Comparison of Phase I and Phase III Duct Tightness Values for North Carolina

Table 3.14. North Carolina Duct Tightness Values in Phase I and Phase III (adjusted)

Duct Tightness	Phase I			Phase III			
	CZ3	**CZ4**	**Statewide**	**CZ3**	**CZ4**	**CZ5**	**Statewide**
Requirement	6	6	6	6	6	6	6
Observations							
Number	32	35	67	39	38	2	79
Range	9.9 to 2.5	11.4 to 0	14.4 to 0	11.9 to 0.0	24.5 to 0.0	13.8 to 6.2	24.5 to 0.0
Average	5.9	5.3	5.6	5.4	7.4	10	6.5
Compliance Rate	18 of 32 (56%)	25 of 35% (71%)	43 of 67 (64%)	25 of 39 (64%)	16 of 38 (42%)	0 of 2 (0%)	41 of 79 (52%)

- **Interpretations:**
  - Overall, 36% of the Phase I observations failed to meet the requirement for duct tightness based on the total duct tightness test. This percentage increased to 48% in Phase III.
  - Reductions in duct leakage represent a continued savings opportunity.

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 North Carolina field study is contained in Appendix C. The full data set is also available on the DOE Building Energy Codes Program website.[5]

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 3.15. Average Home

Home Statistics	Phase I	Phase III
Average square footage (ft^2)	2730	2411
Number of stories	1.8	1.8

3.1.2.2 Compliance

In Phase I, the majority of homes were permitted under the 2012 NC Energy Code (99.6%). In Phase III, all homes were permitted under the 2012 NC Energy Code. Approximately one third of the homes (32%) participated in an above-code program in Phase I and 47% in Phase III.

3.1.2.3 Envelope

Table 3.16. Envelope

Requirement	Phase I	Phase III
Profile		
Walls	All wood-framed with mix of 4” (86%) and 6” (14%) (n=207)	All wood-framed with mix of 4” (80%) and 6” (19%) (n=98)
Foundations	n=249	n=134
Basement	8%	8%
Slab-on-grade	55%	57%
Crawl space	37%	35%
Insulation labeled	88% (n=114)	91% (n=89)
Lighting fixtures sealed	93% (n=97)	78% (n=45)
Utility penetrations sealed	89% (n=79)	89% (n=53)
Knee walls sealed	95% (n=55)	72% (n=36)
Behind bathroom tubs and showers sealed	81% (n=91)	88% (n=58)

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

3.1.2.4 Duct & Piping Systems

Table 3.17. Duct and Piping Systems

Requirement	Phase I	Phase III
Profile		
Supply ducts located within conditioned space (percentage of duct system)	30% (n=154)	27.5% (n=152)
Return ducts located within conditioned space (percentage of duct system)	32% (n=178)	27.4% (n=153)
Supply ducts entirely within conditioned space (percentage of homes and number)	7% (13 homes)	6% (9 homes)
Return ducts entirely within conditioned space (percentage of homes and number)	10% (16 homes)	6% (9 homes)
Duct Insulation	R- 8.0 (n=381)	R-8 (n=323)
Pipe Insulation	R-3.3 (n=8)	R-3.3 (n=47)
Building cavities not used as supply ducts	95% (n=78)	91% (n=76)
Air handlers sealed	90% (n=162)	89% (n=83)
Filter boxes sealed	95% (n=59)	94% (n=69)

3.1.2.5 HVAC Equipment

Table 3.18. HVAC Equipment

Requirement	Phase I	Phase III
Profile		
Heating equipment type	Almost split evenly between gas furnaces and heat pumps (n=177, 96 gas furnace, 77 electric heat pump, 4 electric furnace, 1 electricity unspecified)	Mostly heat pumps (n=136, 69 electric heat pumps, 7 heat pumps as secondary units in homes with predominantly gas heat, 58 gas furnace,1 electric furnace, 1 unknown fuel furnace)
Heating equipment efficiency	84 AFUE furnace, 12.6 HSPF heat pump (n=80 total)	84 AFUE furnace, 9 HSPF heat pump (n=104)
Cooling equipment type	Majority central AC (n=164, 64 heat pump, 99 central AC)	Split between central AC and heat pump (n=120, 65 central AC, 55 heat pump)
Cooling equipment efficiency	14 SEER	14.4 SEER
Water heating equipment type	Mostly electric storage (n=108, 60 electric storage, 30 gas storage, 16 gas tankless, 2 electric tankless)	Mostly electric resistance storage (n=66, 33 electric resistance storage, 18 gas storage, 3 electric heat pump storage, 11 gas tankless, 1 oil storage)
Water heating equipment capacity	53 gallons (n= 88)	49 gallons (n=55)

Requirement	Phase I	Phase III
Water heating equipment efficiency	EF 0.89 (n=3)	EF 0.83 for non-heat pump systems, EF 3.42 for heat pump (n=61)

Successes

- Programmable thermostats were installed 100% in Phase I and 90% in Phase III.
- User manuals for mechanical systems were provided 86% in Phase I and 89% in Phase III.

3.2 Energy Intensity

The statewide energy analysis results in Figure 3.14 show the change in statewide EUI between Phase I and Phase III is trending in the wrong direction. The observed data set (as gathered in the field) was compared against the same set of homes meeting prescriptive code requirements. The average energy consumption overall was lower than a code-compliant home but increased slightly between Phase I and Phase III. Table 3.19 compares the Phase I and Phase III results.

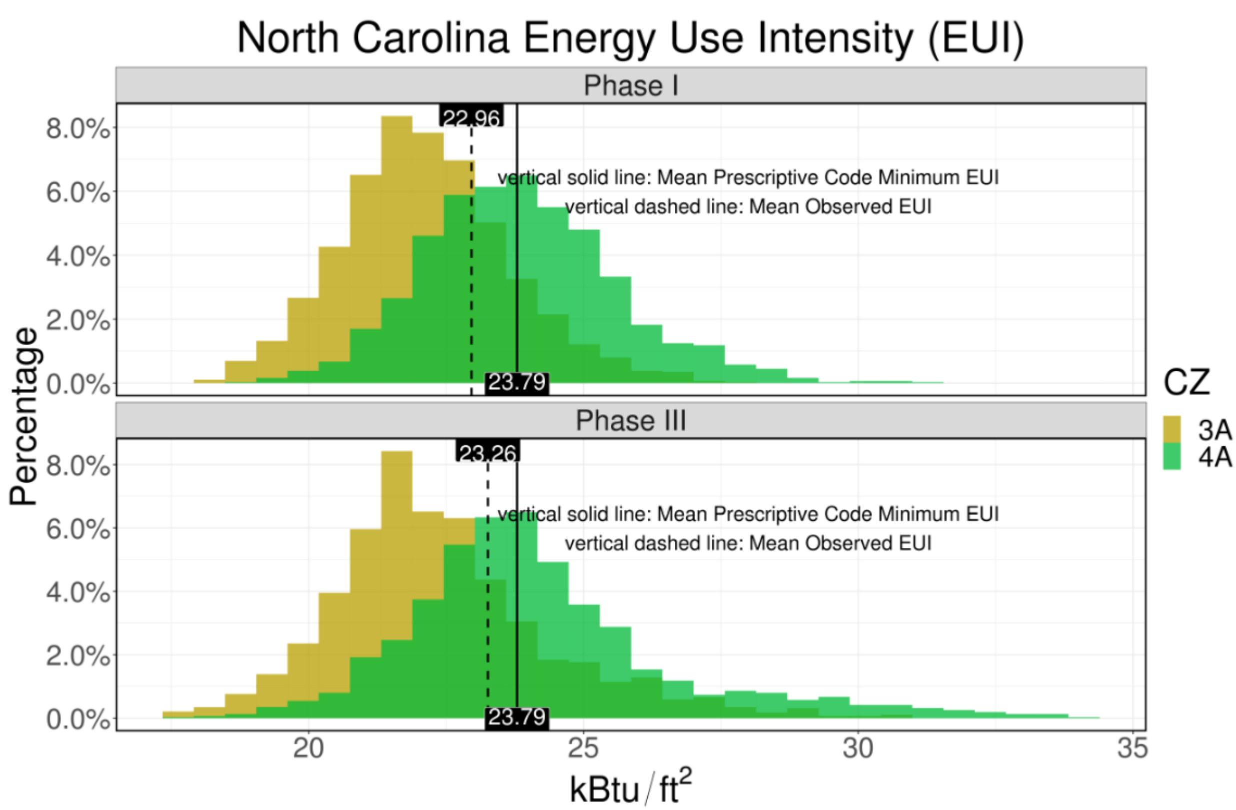

Figure 3.14. Comparison of Phase I and Phase III Statewide EUI for North Carolina

Table 3.19. North Carolina 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)
23.79	22.96	-3.5%	23.26	-2.2%	+1.3%

3.3 Savings Potential

Several key items in Phase I were previously identified as targets for improvement 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.

Table 3.20. Comparison of Phase I and Phase III Compliance Rates by Measure in North Carolina

Measure	Phase I Compliance Rate	Phase III Compliance Rate	Phase III to Phase I Difference in Compliance Rate
Duct Tightness[8]	62%	52%	-10%
Ceiling Insulation	64%	71%	+7%
Envelope Air Tightness	88%	76%	-12%
Lighting	57%	70%	+13%
Exterior Wall Insulation	48%	65%	+17%
Foundations			
Slabs-on Grade	88%	95%	+7%
Floors	60%	62%	+2%

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 3.21. The results indicate that the Phase II education and training activities were successful in reducing the overall savings potential for lighting, exterior wall, ceiling, and foundation insulation. Improvement is achieved through a reduction in measure-level savings potential between Phase I and Phase III. Savings potential for duct tightness and envelope air tightness is trending in the wrong direction.

[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
[8] This compliance rate is for adjusted duct leakage observations.

Table 3.21. Comparison of Phase I and Phase III Estimated Annual Statewide Savings Potential

Measure	Potential Total Energy Savings (MMBtu)		Potential Total Energy Cost Savings ($)		Potential Total State Emissions Reduction (MT CO2e)	
	Phase I	Phase III	Phase I	Phase III	Phase I	Phase III
Lighting	13,822	7,929	$520,839	$298,634	27,211	15,617
Exterior Wall Insulation	20,318	16,978	$390,827	$326,455	11,752	9,837
Duct Tightness	15,720	31,803	$334,527	$677,227	11,507	23,383
Ceiling Insulation	24,918	21,557	$503,364	$435,289	16,256	14,058
Envelope Air Tightness	12,174	32,347	$211,315	$561,908	5,375	14,213
Foundation Insulation*	3,925	4,070	$65,086	$68,531	1,504	1,625
TOTAL	**90,877**	**114,685**	**$2,025,958**	**$2,368,044**	**73,605**	**78,733**

*For North Carolina, foundation insulation is represented by slab-on-grade insulation.

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 3.22). 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 how the total savings and emissions reductions accumulate over 5, 10, and 30 years of construction.

Table 3.22. Comparison of Five-year, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Potential Phase III vs. Phase I

Measure	Potential Total Energy Cost Savings ($) 5 yr		Potential Total Energy Cost Savings ($) 10 yr		Potential Total Energy Cost Savings ($) 30 yr	
	Phase I	Phase III	Phase I	Phase III	Phase I	Phase III
Lighting	$7,812,585	$4,479,510	$28,646,145	$16,424,870	$242,190,135	$138,864,810
Exterior Wall Insulation	$5,862,405	$4,896,825	$21,495,485	$17,955,025	$181,734,555	$151,801,575
Duct Tightness	$5,017,905	$10,158,405	$18,398,985	$37,247,485	$155,555,055	$314,910,555
Ceiling Insulation	$7,550,460	$6,529,335	$27,685,020	$23,940,895	$234,064,260	$202,409,385
Envelope Air Tightness	$3,169,725	$8,428,620	$11,622,325	$30,904,940	$98,261,475	$261,287,220
Foundation Insulation	$976,290	$1,027,965	$3,579,730	$3,769,205	$30,264,990	$31,866,915
TOTAL	**$30,389,370**	**$35,520,660**	**$111,427,690**	**$130,242,420**	**$942,070,470**	**$1,101,140,460**

4.0 Conclusions

North Carolina's field study achieved reductions in lighting and ceiling, wall and foundation insulation savings potential. However, duct tightness and envelope air tightness were trending in the wrong direction, which resulted overall in an increase in savings potential (a reduction in savings potential equates to improvement).

At the time of the study, the state had the 2012 North Carolina Energy Code, which is an amended version of a draft of the 2012 IECC. Based on this study's findings, a prototypical, newly constructed home in North Carolina consumes 2.2 percent less energy than a home exactly meeting the state energy code. As shown in Table 4.1, energy use increased slightly between Phases I and III (1.3%).

Table 4.1. Average Modeled Energy Use Intensity in North Carolina (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)
23.79	22.96	-3.5%	23.26	-2.2%	+1.3%

This results in an unfavorable increase in estimated annual statewide cost savings potential of nearly 17 percent following the Phase II targeted education and training activities (Table 4.2).[2]

Table 4.2. Estimated Annual Statewide Cost Savings Potential

Measure	% Change Phase III vs. I
Lighting	42.7%
Exterior Wall Insulation	16.5%
Duct Tightness	-102.4%
Ceiling Insulation	13.5%
Envelope Air Tightness	-165.9%
Foundation Insulation	-5.3%
TOTAL	**-16.9%**

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

[1] Calculated based on the minimum prescriptive requirements of the state energy code.
[2] See Table 3.21 for potential total energy cost savings in each phase.

5.0 References

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Appendix A

Stakeholder Participation

Appendix A

Stakeholder Participation

Table A.1. Stakeholder Participation in Project Kickoff Meeting

Stakeholder	Description
Appalachian State Energy Center	The mission of the Appalachian Energy Center (AEC) is to conduct applied research and to provide services and education in support of the development and deployment of clean energy technologies, policies, and economies. The AEC team coordinated and held the meeting.
Duke Energy	An electric power holding company headquartered in Charlotte, North Carolina.
NC Homebuilders Association	A trade association consisting of builder and associate member-firms and a network of local builder associations and chapters throughout North Carolina; affiliated with the National Association of Home Builders.
NC Department of Insurance	A state agency that regulates the insurance industry and also houses the Office of State Fire Marshal. The Insurance Commissioner serves as State Fire Marshal and duties include helping to improve building codes.
NC Building Performance Association	A not-for-profit association of North Carolina home and building performance professionals and companies seeking to lead high performance construction in the state through quality construction, workforce development, political advocacy, public education and more.
North Carolina Clean Energy Technology Center	A UNC System-chartered Public Service Center administered by the College of Engineering at North Carolina State University. Its mission is to advance a sustainable energy economy by educating, demonstrating and providing support for clean energy technologies, practices, and policies.
North Carolina Sustainable Energy Association	A non-profit membership organization working on public policy change and driving market development.
Greenville Utilities	A municipal electric utility company in eastern North Carolina.
PSNC Energy	A natural gas utility company with offices in Raleigh.
Piedmont Natural Gas	A natural gas utility company with offices in Charlotte.
Yellow Dot	A major HVAC contractor for new homes in North Carolina.
Energy efficient builders	Several homebuilders who specialize in high efficiency homes attended.
Above and Beyond Energy	Eastern and central NC Home Energy Rating company
Environmental Solutions Group	Central NC Home Energy Rating company

Appendix B

State Sampling Plan

Appendix B

State Sampling Plan

Table B.1. Phase I State Sampling Plan

Location	Sample	Actual
Asheville, Buncombe	1	1
Beaufort County Unincorporated Area, Beaufort	1	1
Brunswick County Unincorporated Area, Brunswick	1	1
Burlington, Alamance	1	1
Cabarrus County, Cabarrus	3	3
Cary town, Wake	4	4
Cumberland County Unincorporated Area, Cumberland	2	2
Durham, Durham	3	3
Fayetteville, Cumberland	1	1
Forsyth County Unincorporated Area, Forsyth	3	3
Fuquay-Varina town, Wake	2	2
Gaston County Unincorporated Area, Gaston	1	1
Greensboro, Guilford	2	2
Guilford County Unincorporated Area, Guilford	1	1
Haywood County Unincorporated Area, Haywood	1	1
Henderson County, Henderson	1	1
High Point, Guilford	1	1
Iredell County, Iredell	2	2
Jacksonville, Onslow	1	1
Leland town, Brunswick	1	1
Mecklenburg County, Mecklenburg	6	6
Montgomery County, Montgomery	1	1
Morrisville town, Wake	1	1
New Hanover County Unincorporated Area, New Hanover	2	2
Onslow County Unincorporated Area, Onslow	3	3
Pender County Unincorporated Area, Pender	1	1
Raleigh, Wake	3	3
Southern Pines town, Moore	1	1
Southport, Brunswick	1	1
Transylvania County, Transylvania	1	1
Union County Unincorporated Area, Union	1	1
Wake County Unincorporated Area, Wake	3	3
Wake Forest town, Wake	3	3
Waxhaw town, Union	2	2
Winston-Salem, Forsyth	1	1
Totals	**63**	**63**

Table B.2. Phase III State Sampling Plan

Location	Sample	Actual
Asheville, Buncombe	1	1
Buncombe County Unincorporated Area, Buncombe County	2	2
Burke County Unincorporated Area, Burke County	1	1
Burlington, Alamance County	1	1
Caldwell County Unincorporated Area, Caldwell County	1	1
Cabarrus County, Cabarrus County	3	3
Cary Town, Wake County	1	1
Chatham County Unincorporated Area, Chatham County	2	2
Clayton Town, Johnston County	1	1
Craven County Unincorporated Area	1	1
Durham, Durham County	2	2
Fayetteville, Cumberland County	3	3
Fuquay-Varina Town, Wake County	3	3
Gastonia, Gaston County	1	1
Harnett County Unincorporated Area, Harnett County	1	1
Henderson County, Henderson County	2	2
Holly Springs Town, Wake County	1	1
Jackson County, Jackson County	1	1
Johnston County Unincorporated Area, Johnston County	1	1
Lincoln County, Lincoln County	2	2
Mecklenburg County, Mecklenburg County	8	8
Moore County Unincorporated Area, Moore county	1	1
Nash County Unincorporated Area, Nash County	1	1
New Hanover County Unincorporated Area, New Hanover County	1	1
Pender County Unincorporated Area, Pender County	1	1
Raleigh, Wake County	3	3
Randolph County Unincorporated Area, Randolph County	1	1
Robeson County Unincorporated Area, Robeson County	1	1
Union County Unincorporated Area, Union County	3	3
Wake Forest Town, Wake County	2	2
Watagua County Unincorporated Area, Watauga County	2	2
Wayne County Unincorporated Area, Wayne County	1	1
Wendell Town, Wake County	2	2
Winston-Salem, Forsyth County	1	1
Totals	**63**	**63**

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 North Carolina 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)	2730	2411
Number of Stories	1.8	1.8
Number of Homes Visited	249	134

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)	0.4%	21.6%	44.2%	25.1%	8.7%
Percentage (Phase III)	0%	28%	50%	17%	5%

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

Table C.3. Number of Stories

No. of Stories	1	1.5	2	2.5	3	4+
Percentage (Phase I)	15.9%	16.7%	61.8%	2.0%	3.3%	0.4%
Percentage (Phase III)	18%	7%	73%	0%	2%	0%

Table C.4. Number of Bedrooms

No. of Bedrooms	1	2	3	4	5+
Percentage (Phase I)	12%	0%	7%	77%	0.5%
Percentage (Phase III)	0%	5%	42%	38%	15%

C.1.1.2 Wall Profile

Table C.5. Wall Characteristics

Wall Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Framing Type			238	103
Frame Walls	100%	100%		
Mass Walls	0%	0%		
Framing Material			223	96
Wood	100%	99%		
Steel	0%	1%		
Framing Depth			207	98
4 inch	86%	80%		
6 inch	14%	19%		
Type of Wall Insulation			74	65
Cavity Only	100%	95%		
Cavity + Continuous	0%	5%		
Continuous Only	0%	0%		

C.1.1.3 Foundation Profile

Table C.6. Foundation Characteristics

Foundation Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Foundation Type			249	134
Basement	8%	8%		
Slab on Grade	55%	57%		
Crawlspace	37%	35%		

Foundation Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Basement Type			15	11
Conditioned	47%	45%		
Unconditioned	53%	55%		

C.1.1.4 Builder Profile

Table C.7. Builder Characteristics

Builder Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Number of Homes Built Annually	227	579*	90	84
Distribution of Number of Homes Built Annually			90	84
Less than 10	4%	2 %		
10 to 50	32%	30 %		
50 to 99	10%	6 %		
100+	55%	62 %		

* Average includes one observation of 26,563.

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.8. Energy Code and Above Code Programs

Code or Above Code Program Used	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Energy Code Used			248	132
2009 IECC	0.4%	0%		
2012 NC	99.6%	100%		
Was home participating in an above code program?			31	30
Yes	32%	47%		
No	69%	53%		
Which above code program?			11	14
Energy Star for Homes	18%	29%		
HERS	18%	0%		
Eco Select	9%	14%		
NAHB Green	9%	7%		
System Vision	9%	14%		

Code or Above Code Program Used	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Duke Energy HERO	36%	29%		
HauSmart	0%	7%		

Table C.9. Compliance Path Used

Compliance Path Used	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
			45	42
Prescriptive	89%	93%		
RES*check*	9%	2%		
Performance	2%	5%		

C.1.3 Envelope

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

Table C.10. 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?			114	89
Yes	88%	91%		
No	12%	9%		
Did the attic hatch/door exhibit the correct insulation value?			18	19
Yes	NA*	26%		
No	NA*	74%		
Air Sealing in accordance with checklist[1]				
Openings around doors and windows sealed?	92%	92%	74	64
Utility penetrations sealed?	89%	89%	79	53
Dropped ceilings sealed?	86%	80%	70	56
Ceiling systems under knee walls sealed?	95%	72%	55	36
Garage walls sealed?	81%	88%	91	58
Tubs and showers sealed?	81%	88%	74	54
Other sources of infiltration sealed?	74%	67%	86	18
IC-rated light fixtures sealed?	93%	78%	97	45

*In Phase I responses were not Yes/No; of the 18 responses, 2 were "did not comply", and the remaining 16 were R-values ranging from R-0 to R-38, with an average of R-16.

[1] Note that results in this section are from checklist items that are addressed via visual inspection. When comparing these visual results with the actual tested results, it is clear that there can be significant differences in the two methods.

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.11. 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	30%	27%	184	152
Return	32%	27%	178	153
Ducts entirely in conditioned space (number and percentage)				
Supply	13 duct systems (7%)	9 duct systems (6%)		
Return	17 duct systems (10%)	9 duct systems (6%)		
Ducts in unconditioned space insulation (R-value)				
Supply	8	8	190	60
Return	8	8	191	60
Ducts in attic insulation (R-value)				
Supply	NA*	7.9	NA*	101
Return	NA*	7.9	NA*	102
Pipe insulation (R-value)			8	48
Average	R-3.3	R-3.2		
Range	R-0 to R-5	R-0 to R-9		
Building cavities used as supply ducts	5%	9%	78	76
Air ducts sealed	97%	93%	156	56
Air handlers sealed	90%	89%	162	83
Filter boxes sealed	95%	94%	59	69

*Ducts in attic insulation R-value not on data collection form in Phase I.

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.12. Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			177	110
Gas	54%	47%		
Electricity	56%	57%		
System Type			177	110
Furnace	56%	48%		
Heat Pump	44%	52%		
Average System Capacity			28	87
Furnace	72,000 Btu/hr	56,600 Btu/hr		
Heat Pump	42,700 Btu/hr	29,900 Btu/hr		
Average System Efficiency			79	104
Furnace	84 AFUE	84.5 AFUE		
Heat Pump	12.6 HSPF	8.5 HSPF		

C.1.5.2 Cooling

Table C.13. Cooling Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			164	120
Central AC	60%	54%		
Heat Pump	40%	46%		
Average System Capacity			47	73
Central AC	45,300 Btu/hr	35,600 Btu/hr		
Heat Pump	36,800 Btu/hr	29,600 Btu/hr		
Average System Efficiency	13.9 SEER	14.4	52	95

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

C.1.5.3 Water Heating

Table C.14. Water Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			112	68
Gas	42%	44%		
Electricity	58%	54%		
Oil	NA	1.5%		

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			108	66
Storage	85%	83%		
Tankless	15%	17%		
Average System Capacity	53 gal	47	88	61

C.1.5.4 Ventilation

Table C.15. Ventilation Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			18	39
Exhaust Only	28%	59%		
AHU-Integrated	33%	18%		
Standalone ERV/HRV	11%	18%		
Standalone ERV	6%	NA		
Supply Only	NA	5%		
Exhaust Fan Type			3	23
Dedicated Exhaust	0%	4%		
Bathroom Fan	100%	96%		

C.1.5.5 Other

Table C.16. Other Mechanical System Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Mechanical Manuals Provided	86%	89%	102	54
Programmable Thermostat Installed	100%	90%	65	41

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 North Carolina. Also included are multi-year (5-year, 10-year, and 30-year) aggregations of the annual results in Table D.3, Table D.4, and Table D.5. The multi-year savings reflect the same reductions and increases as the annual savings and are simply the annual savings multiplied by 15, 55, and 465 for 5-year, 10-year, and 30-year savings, respectively. For analytical details refer to Section 2.3.3 (Savings Analysis) or the methodology report (DOE 2018).

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

Measure	Climate Zone	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Lighting*	3A	172	-1	467	15,585	7,278	272,595	14,202
	4A	170	-1	453	14,444	6,545	248,239	13,009
	State Total	**171**	**-1**	**460**	**30,029**	**13,822**	**520,839**	**27,211**
Exterior Wall Insulation	3A	43	2	390	15,585	6,074	117,542	3,575
	4A	106	6	987	14,444	14,252	273,428	8,177
	State Total	**73**	**4**	**677**	**30,029**	**20,318**	**390,827**	**11,752**
Duct Tightness	3A	69	3	514	15,585	8,016	168,649	5,734
	4A	75	3	533	14,444	7,704	165,886	5,774
	State Total	**72**	**3**	**523**	**30,029**	**15,720**	**334,527**	**11,507**
Ceiling Insulation	3A	75	4	609	15,585	9,498	192,624	6,240
	4A	130	6	1,068	14,444	15,425	310,856	10,015
	State Level	**102**	**5**	**830**	**30,029**	**24,918**	**503,364**	**16,256**
Envelope Air Tightness	3A	30	3	371	15,585	5,777	99,705	2,511
	4A	37	3	443	14,444	6,398	111,627	2,863

	State Total	**33**	**3**	**405**	**30,029**	**12,174**	**211,315**	**5,375**
Foundation Insulation	3A	0	0	0	8,869	0	0	0
	4A	34	4	478	8,219	3,929	65,143	1,504
	State Total	**16**	**2**	**230**	**17,088**	**3,925**	**65,086**	**1,504**
TOTAL		**467**	**16**	**3,125**	**Varies**	**90,877**	**2,025,958**	**73,605**

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

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

Measure	Climate Zone	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Lighting*	3A	99	-1	268	15,585	4,175	156,314	8,152
	4A	98	-1	260	14,444	3,754	142,320	7,464
	State Total	**98**	**-1**	**264**	**30,029**	**7,929**	**298,634**	**15,617**
Exterior Wall Insulation	3A	41	1	373	15,585	5,820	112,559	3,421
	4A	83	5	773	14,444	11,158	213,896	6,416
	State Total	**61**	**4**	**565**	**30,029**	**16,978**	**326,455**	**9,837**
Duct Tightness	3A	140	6	1,042	15,585	16,240	341,834	11,639
	4A	153	6	1,077	14,444	15,563	335,393	11,743
	State Total	**146**	**6**	**1,059**	**30,029**	**31,803**	**677,227**	**23,383**
Ceiling Insulation	3A	63	3	508	15,585	7,919	160,486	5,208
	4A	115	6	944	14,444	13,639	274,803	8,850
	State Level	**88**	**4**	**718**	**30,029**	**21,557**	**435,289**	**14,058**
Envelope Air Tightness	3A	79	7	985	15,585	15,352	265,149	6,630
	4A	98	8	1,177	14,444	16,995	296,758	7,583
	State Total	**88**	**8**	**1,077**	**30,029**	**32,347**	**561,908**	**14,213**

Foundation Insulation	3A	0	0	0	8,869	0	0	0
	4A	37	4	495	8,219	4,070	68,531	1,625
	State Total	**18**	**2**	**238**	**17,088**	**4,070**	**68,531**	**1,625**
TOTAL		**499**	**22**	**3,921**	**Varies**	**114,685**	**2,368,044**	**78,733**

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

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

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
	5yr	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Lighting	207,330	760,210	6,427,230	$7,812,585	$28,646,145	$242,190,135	408,163	1,496,599	12,653,066
Exterior Wall Insulation	304,770	1,117,490	9,447,870	$5,862,405	$21,495,485	$181,734,555	176,282	646,366	5,464,734
Duct Tightness	235,800	864,600	7,309,800	$5,017,905	$18,398,985	$155,555,055	172,610	632,905	5,350,923
Ceiling Insulation	373,770	1,370,490	11,586,870	$7,550,460	$27,685,020	$234,064,260	243,837	894,069	7,558,944
Envelope Air Tightness	182,610	669,570	5,660,910	$3,169,725	$11,622,325	$98,261,475	80,619	295,603	2,499,192
Foundation Insulation	58,875	215,875	1,825,125	$976,290	$3,579,730	$30,264,990	22,564	82,736	699,496
TOTAL	**1,363,155**	**4,998,235**	**42,257,805**	**$30,389,370**	**$111,427,690**	**$942,070,470**	**1,104,076**	**4,048,279**	**34,226,355**

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

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
	5yr	10yr	30yr	5yr	10yr	30yr	5yr	10yr	30yr
Lighting	118,935	436,095	3,686,985	$4,479,510	$16,424,870	$138,864,810	234,255	858,935	7,261,905
Exterior Wall Insulation	254,670	933,790	7,894,770	$4,896,825	$17,955,025	$151,801,575	147,555	541,035	4,574,205
Duct Tightness	477,045	1,749,165	14,788,395	$10,158,405	$37,247,485	$314,910,555	350,745	1,286,065	10,873,095
Ceiling Insulation	323,355	1,185,635	10,024,005	$6,529,335	$23,940,895	$202,409,385	210,870	773,190	6,536,970
Envelope Air Tightness	485,205	1,779,085	15,041,355	$8,428,620	$30,904,940	$261,287,220	213,195	781,715	6,609,045
Foundation Insulation	61,050	223,850	1,892,550	$1,027,965	$3,769,205	$31,866,915	24,375	89,375	755,625
TOTAL	**1,720,275**	**6,307,675**	**53,328,525**	**$35,520,660**	**$130,242,420**	**$1,101,140,460**	**1,180,995**	**4,330,315**	**36,610,845**

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

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
	5yr	10yr	30yr	5yr	10yr	30yr	5yr	10yr	30yr
Lighting	88,395	324,115	2,740,245	$3,333,075	$12,221,275	$103,325,325	173,908	637,664	5,391,161
Exterior Wall Insulation	50,100	183,700	1,553,100	$965,580	$3,540,460	$29,932,980	28,727	105,331	890,529
Duct Tightness	-241,245	-884,565	-7,478,595	-$5,140,500	-$18,848,500	-$159,355,500	-178,135	-653,160	-5,522,172
Ceiling Insulation	50,415	184,855	1,562,865	$1,021,125	$3,744,125	$31,654,875	32,967	120,879	1,021,974
Envelope Air Tightness	-302,595	-1,109,515	-9,380,445	-$5,258,895	-$19,282,615	-$163,025,745	-132,576	-486,112	-4,109,853
Foundation Insulation	-2,175	-7,975	-67,425	-$51,675	-$189,475	-$1,601,925	-1,811	-6,639	-56,129
TOTAL	**-357,120**	**-1,309,440**	**-11,070,720**	**-$5,131,290**	**-$18,814,730**	**-$159,069,990**	**-76,919**	**-282,036**	**-2,384,490**

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