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Kentucky Residential Energy Code Field Study: Final Report

September 2022

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U.S. DEPARTMENT OF ENERGY

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

Executive Summary

A research project in the Commonwealth of Kentucky 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 Kentucky 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 April 2015 and continued through August 2015. During this period, research teams visited 140 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 Kentucky homes, and indicated over $1,200,000 in potential annual savings to homeowners in the state that could result from increased code compliance (Table ES.2).

Starting in March 2015 and continuing through May 2017, members of the Kentucky field study team conducted targeted education and training activities (Phase II). Those activities included circuit rider assistance[1], in-person trainings, an energy code hotline, and online videos. 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 128 homes across the state between May 2017 and September 2017. The results of this effort are presented Table ES.1 and discussed further in Section 3.0.

Methodology

The project team was led by the Midwest Energy Efficiency Alliance (MEEA) who partnered with the Kentucky Department of Housing, Buildings and Construction (state code agency) and the Kentucky Department of Energy Development and Independence (state energy office), with support from Cadmus Group (Cadmus). 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.

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

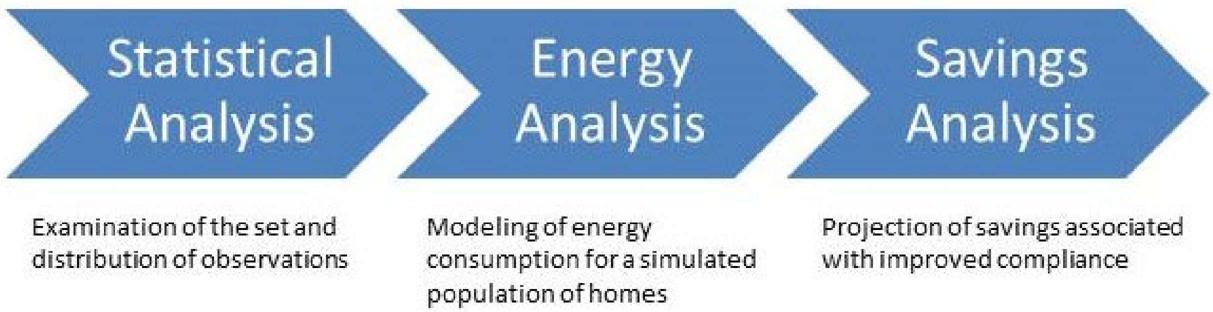

Figure ES.1. Stages of Analysis Applied in the Study

Results

As shown in Table ES.1, a measurable change was detected in statewide energy use between Phase I and Phase III. The Phase I analysis indicated homes used about 7.9 percent less energy than would be expected relative to homes built to the current state code. This percentage improved to 13.2 percent in Phase III, representing a change in EUI of approximately 5.8 percent (1.82 kBtu/ft^2) between Phases I and III.

Table ES.1. Average Modeled Energy Use Intensity in Kentucky (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)
33.98	31.31	-7.9%	29.49	-13.2%	-5.8%

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

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

statistical trends were then extrapolated based on projected new construction across the state. These items, as identified in the Phase I baseline field study, were targeted as a focal point for Phase II education and training activities, and then reassessed following the Phase III study to examine whether a measurable change was detected. In this case, improvement is achieved through a *reduction* in measure-level savings potential between Phases I and III.

Table ES.2. Estimated Annual Statewide Savings Potential

	Total Energy Cost Savings ($)		$ Change	% Change
Measure	**Phase I**	**Phase III**	**Phase III vs. Phase I**	**Phase III vs. I**
Envelope Air Tightness	484,314	10,321	473,993	97.9%
Ceiling Insulation	215,656	91,786	123,870	57.4%
Exterior Wall Insulation	171,044	151,974	19,070	11.1%
Foundation Insulation	108,156	178,905	-70,749	-65.4%
Lighting	197,544	153,383	44,161	22.4%
Duct Tightness	43,142	342,217	-299,075	-793%
TOTAL	$1,219,856	$928,585	$291,271	23.9%

Although energy cost savings potential increased (unfavorable) for foundation insulation and duct tightness, overall there was a reduction in savings potential between Phase I and Phase III. This is an improvement of nearly 24 percent and nearly $300,000 in annual cost savings achieved by Phase II targeted education and training activities. Therefore, Kentucky meets the metrics for a successful project. However, while successful, the project does leave open unanswered questions such as the possible reasons for the increase in energy savings potential for duct tightness. More research would be required to determine the actual root causes of this increase. Possible causes include poor workmanship, inconsistent use of testing protocols, incorrect placement of duct testing equipment, or inconsistent training of testers.

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

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- Kelsey Horton, *MEEA*
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- Ric McNees, *DHBC*
- Lee Colten, *Kentucky Department for Energy Development and Independence (DEDI)*
- Greg Guess, *DEDI*
- George Mann, *Project Manager*
- Larry Mahaffey, *Circuit Rider*
- Eric Makela, [*Britt-Makela Group* in Phase I and *Cadmus* in Phase III]
- Nigel Makela, [*Britt-Makela Group* in Phase I and *Cadmus* in Phase III]
- Jolyn Green, [*Britt-Makela Group* in Phase I and *Cadmus* in Phase III]

MEEA - The Midwest Energy Efficiency Alliance is the Midwest's key proponent and resource for energy efficiency policy, helping to educate and advise a diverse range of stakeholders on ways to pursue a cost-effective, energy-efficient agenda. Through partnerships, programs and a dynamic annual conference, MEEA curates a forward-thinking conversation to realize the economic and environmental benefits of energy efficiency. Learn more at http://www.mwalliance.org/.

DHBC - The Kentucky Department of Housing, Buildings and Construction was established to unite all related functions pertaining to the building industry and to provide a more effective building inspection process. DHBC enforces statewide standards for building construction. See more about DHBC at http://dhbc.ky.gov/.

DEDI - The Kentucky Department for Energy Development and Independence mission is to create efficient, sustainable energy solutions and strategies; protect the environment; create a base for strong economic growth. See more information on DEDI at http://energy.ky.gov/Pages/default.aspx.

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

Acronyms and Abbreviations

AC	air conditioning
ACH	air changes per hour
AFUE	annual fuel utilization efficiency
AHU	air handling unit
Btu	British thermal unit
cfm	cubic feet per minute
CAAK	Code Administrators Association of Kentucky
CFA	conditioned floor area
CO2e	carbon dioxide equivalent
CZ	climate zone
DEDI	Department for Energy Development and Independence
DHBC	Department of Housing, Buildings and Construction
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EF	energy factor
EUI	energy use intensity
FOA	funding opportunity announcement
HBAK	Home Builders Association of Kentucky
HBANK	Home Builders Association of Northern Kentucky
HSPF	heating season performance factor
ICC	International Code Council
IECC	International Energy Conservation Code
IIQ	insulation installation quality
kBtu	thousand British thermal units
KY	Kentucky
MACED	Mountain Association for Community Economic Development
MEEA	Midwest Energy Efficiency Alliance
MMBtu	million British thermal units
MT	metric ton
NA	not applicable
PNNL	Pacific Northwest National Laboratory
ROI	return on investment
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient

Contents

Executive Summary iii
Acknowledgments vi
Acronyms and Abbreviations vii
1.0 Introduction 1.1
 1.1 Background 1.1
 1.2 Project Team 1.2
 1.3 Stakeholder Interests 1.2
2.0 Methodology 2.1
 2.1 Overview 2.1
 2.2 State Study 2.2
  2.2.1 Sampling 2.2
  2.2.2 Data Collection 2.2
 2.3 Data Analysis 2.4
  2.3.1 Statistical Analysis 2.4
  2.3.2 Energy Analysis 2.5
  2.3.3 Savings Analysis 2.5
 2.4 Limitations 2.7
  2.4.1 Applicability of Results 2.7
  2.4.2 Definition and Determination of Compliance 2.7
  2.4.3 Sampling Substitutions 2.7
  2.4.4 Site Access 2.7
  2.4.5 Analysis Methods 2.7
  2.4.6 Presence of Tradeoffs 2.8
 2.5 Phase II Targeted Education and Training 2.8
 2.6 Phase III Field Study and Analysis 2.9
3.0 State Results 3.1
 3.1 Field Observations 3.1
  3.1.1 Key Items 3.1
  3.1.2 Additional Data Items 3.20
 3.2 Energy Use Intensity 3.23
 3.3 Savings Potential 3.24
4.0 Conclusions 4.1
5.0 References 5.1
Appendix A – Stakeholder Participation A.1
Appendix B – State Sampling Plan B.1
Appendix C – Additional Data C.1
Appendix D – Energy Savings D.1

Figures

2.1 Sample Graph ... 2.4
3.1 Comparison of Phase I and Phase III Envelope Tightness for Kentucky ... 3.2
3.2 Comparison of Phase I and Phase III Window SHGC for Kentucky ... 3.3
3.3 Comparison of Phase I and Phase III Window U-Factors for Kentucky ... 3.4
3.4 Comparison of Phase I and Phase III Wall R-Values for Kentucky ... 3.5
3.5 Comparison of Phase I and Phase III Wall U-Factors for Kentucky ... 3.7
3.6 Comparison of Phase I and Phase III Ceiling R-Values for Kentucky ... 3.8
3.7 Comparison of Phase I and Phase III Ceiling U-Factors for Kentucky ... 3.9
3.8 Comparison of Phase I and Phase III High-Efficacy Lighting Percentages for Kentucky ... 3.10
3.9 Comparison of Phase I and Phase III Basement Wall Cavity R-Values for Kentucky ... 3.12
3.10 Comparison of Phase I and Phase III Basement Wall Continuous R-Values for Kentucky ... 3.12
3.11 Comparison of Phase I and Phase III Basement Wall U-Factors for Kentucky ... 3.13
3.12 Comparison of Phase I and Phase III Floor R-Values for Kentucky ... 3.14
3.13 Comparison of Phase I and Phase III Floor U-Factors for Kentucky ... 3.15
3.14 Comparison of Phase I and Phase III Slab R-Values for Kentucky ... 3.16
3.15 Phase III Crawlspace Wall R-values for Kentucky ... 3.17
3.16 Phase III Crawlspace Wall U-Factors for Kentucky ... 3.18
3.17 Comparison of Phase I and Phase III Duct Tightness Values for Kentucky ... 3.19
3.18 Comparison of Phase I and Phase III Statewide EUI for Kentucky ... 3.23

Tables

3.1 Kentucky Envelope Tightness in Phase I and Phase III ... 3.2
3.2 Kentucky Window SHGC in Phase I and Phase III ... 3.3
3.3 Kentucky Window U-Factors in Phase I and Phase III ... 3.4
3.4 Kentucky Wall Cavity R-Values in Phase I and Phase III ... 3.5
3.5 Comparison of Phase I and Phase III Above Grade Wall IIQ for Kentucky ... 3.6
3.6 Kentucky Wall U-Factors in Phase I and Phase III ... 3.7
3.7 Kentucky Ceiling R-Values in Phase I and Phase III ... 3.8
3.8 Comparison of Phase I and Phase III Roof IIQ for Kentucky ... 3.9
3.9 Kentucky Ceiling U-Factors in Phase I and Phase III ... 3.9
3.10 Kentucky High-Efficacy Lighting in Phase I and Phase III ... 3.11
3.11 Basement Wall IIQ Comparison between Phase I and Phase III for Kentucky ... 3.13
3.12 Kentucky Basement Wall U-Factors in Phase I and Phase III ... 3.13
3.13 Floor IIQ Comparison between Phase I and Phase III for Kentucky ... 3.15
3.14 Kentucky Floor U-Factors in Phase I and Phase III ... 3.15

3.15 Kentucky Slab R-Values in Phase I and Phase III 3.16
3.16 Kentucky Crawlspace Wall R-values in Phase III 3.17
3.17 Kentucky Crawlspace Wall U-Factors 3.18
3.18 Kentucky Duct Tightness Values in Phase I and Phase III 3.19
3.19 Average Home 3.21
3.20 Envelope 3.21
3.21 Duct and Piping Systems 3.21
3.22 HVAC Equipment 3.22
3.23 Kentucky Statewide EUI in Phase I and Phase III 3.24
3.24 Comparison of Phase I and Phase III Compliance Rates by Measure in Kentucky 3.24
3.25 Comparison of Phase I and Phase III Estimated Annual Statewide Savings Potential 3.25
4.1 Average Modeled Energy Use Intensity in Kentucky 4.1
4.2 Estimated Annual Statewide Savings Potential 4.1

1.0 Introduction

A three-phase research project in the Commonwealth of Kentucky 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 April 2015 and continued through August 2015. During this period, research teams visited 140 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 Kentucky homes, and indicated over $1,200,000 in potential annual savings to homeowners in the state that could result from increased code compliance.

Starting in March 2015 and continuing through May 2017, members of the Kentucky field study team conducted targeted education and training activities (Phase II). Those activities included circuit rider assistance[1], in-person trainings, an energy code hotline, and online videos. 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 128 homes across the state between May 2017 and September 2017. The results of this effort are presented in Section 3.0. At the time of the study, the state had the 2009 International Energy Conservation Code (IECC) as the statewide energy code. The study methodology, data analysis and resulting findings are presented throughout this report.

1.1 Background

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

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

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

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

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

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

1.2 Project Team

The Kentucky project was led by the Midwest Energy Efficiency Alliance (MEEA), who partnered with the Kentucky Department of Housing, Buildings and Construction (state code agency) and the Kentucky Department of Energy Development and Independence (state energy office), and field data collected by Cadmus. 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

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

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

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

2.0 Methodology

2.1 Overview

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

2.2 State Study

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

2.2.1 Sampling

PNNL developed statewide sampling plans statistically representative of recent construction activity within the state. For Kentucky, Census Bureau permit data[4] were reviewed but deemed inadequate due to the lack of permit reporting in much of the state. It was determined that an alternative data source would more accurately represent current construction trends within the state. In Kentucky every new single-family home is required to get HVAC and plumbing permits. The permit data are kept by the state, and these data was provided to PNNL.[5] The sampling plan specified the number of key item observations required in each randomly selected county (totaling 63 of each key item across the entire state). Kentucky comprises a single climate zone (CZ4), therefore there is no differentiation of results by climate.

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

2.2.2 Data Collection

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

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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).

[5] Three years of data were provided for use in the Phase I sample plan. A new set of data, from 2014, 2015, and 2016 was used for the Phase III sample plan.

2.2.2.1 Data Collection Form

The field teams relied on a data collection form customized to the mandatory and prescriptive requirements of the state energy code (the 2009 IECC with Kentucky-specific amendments[6]). The final data collection form is available in spreadsheet format on the DOE Building Energy Codes Program website.[7] 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[8] 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 included on the form, such as whether the home participated in an above-code program, assisted in understanding whether other influencing factors were 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.[9]

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[6] The Kentucky code is available at http://dhbc.ky.gov/Documents/2013%20KRC%202nd%20Edition%20%28February%202014%29%20-%204.8.2014.pdf.

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

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

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

2.3 Data Analysis

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

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

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

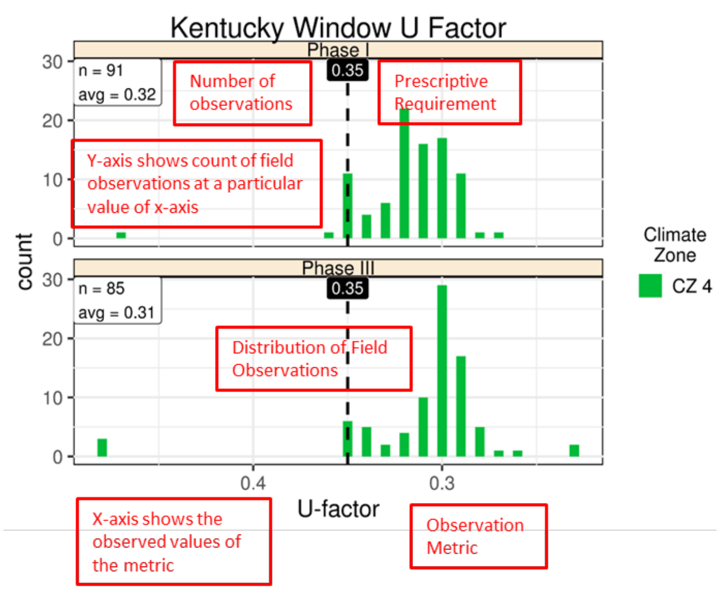

Figure 2.1. Sample Graph

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.[10] 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).[11]

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[12]. For these items, additional models were created to assess the savings potential, comparing what was observed in the

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

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

[12] "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.

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).[13] The worse-than-code observations for the key item under consideration are used to create a second set of models (*as built*) that can be compared to the baseline (*full compliance*) models. All other components were maintained at the corresponding prescriptive code value, allowing for the savings potential associated with a key item to be evaluated in isolation.

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

[13] 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.

collection forms) were updated to help guide future data collection teams in proactively identifying potential outliers and to the greatest extent possible verifying (or mitigating) their impacts in the field.

2.4 Limitations

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

2.4.1 Applicability of Results

An inherent limitation of the study design is that the results (key item distributions, EUI, and measure-level savings) can be considered statistically significant only at the state level. 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 Kentucky, specific Phase II activities included:

- Circuit rider: The circuit rider was the focus of the Phase II intervention activities and provided support to individual stakeholders (e.g., code officials and builders) that was supplemented with the in-person trainings, online training program, and energy code assistance hotline. The circuit rider proactively reached out to and met with code officials and builders at their businesses or construction sites. The intent was for the circuit rider "to become a trusted advisor on energy code issues" (MEEA 2018). Return visits were made offering more detailed and in-depth assistance. Kentucky's circuit rider was a retired code official from western Kentucky. Circuit rider assistance included 203 "one-on-one meetings," with code officials or builders, with a total of 312 attendees. There were also an additional 350 "in-field contacts" where 209 code books, 661 compliance guides, and 249 energy stickers (a Kentucky-specific version of the energy panel certificate) were disseminated.

- In-person training: Full-day classes were offered across the state on air sealing and insulation principles, common compliance challenges, and HVAC design and sizing principles. Fourteen in-person trainings were held at various locations to 424 attendees[14].
- Online videos: Several online videos were created and had over 950 views[15].
- Online energy code assistance hotline: A hotline and email inquiry resource line was provided that promised a response from the circuit rider within 24 hours.
- Other: The project was also presented at various other venues to approximately 1,160 people.

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. Since Kentucky has a single climate zone and a code that did not change during the course of the study, items #2, 5, and 6 above were not applicable.

[14] https://www.mwalliance.org/initiatives/policy/kentucky/residential-energy-code-improvement-study
[15] https://www.youtube.com/playlist?list=PLkWlq0Kgprm7oXX5zm6_Jh6l6mlnU6TTv

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 three main foundation types observed were conditioned basements, floors, and slabs. In addition, there were four crawlspace wall observations in Phase I, but due to that small number, graphics were only provided for conditioned basements, floors, and slabs in Phase I. There were additional observations of crawlspace walls in Phase III, so crawlspace wall plots are provided for Phase III.

[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

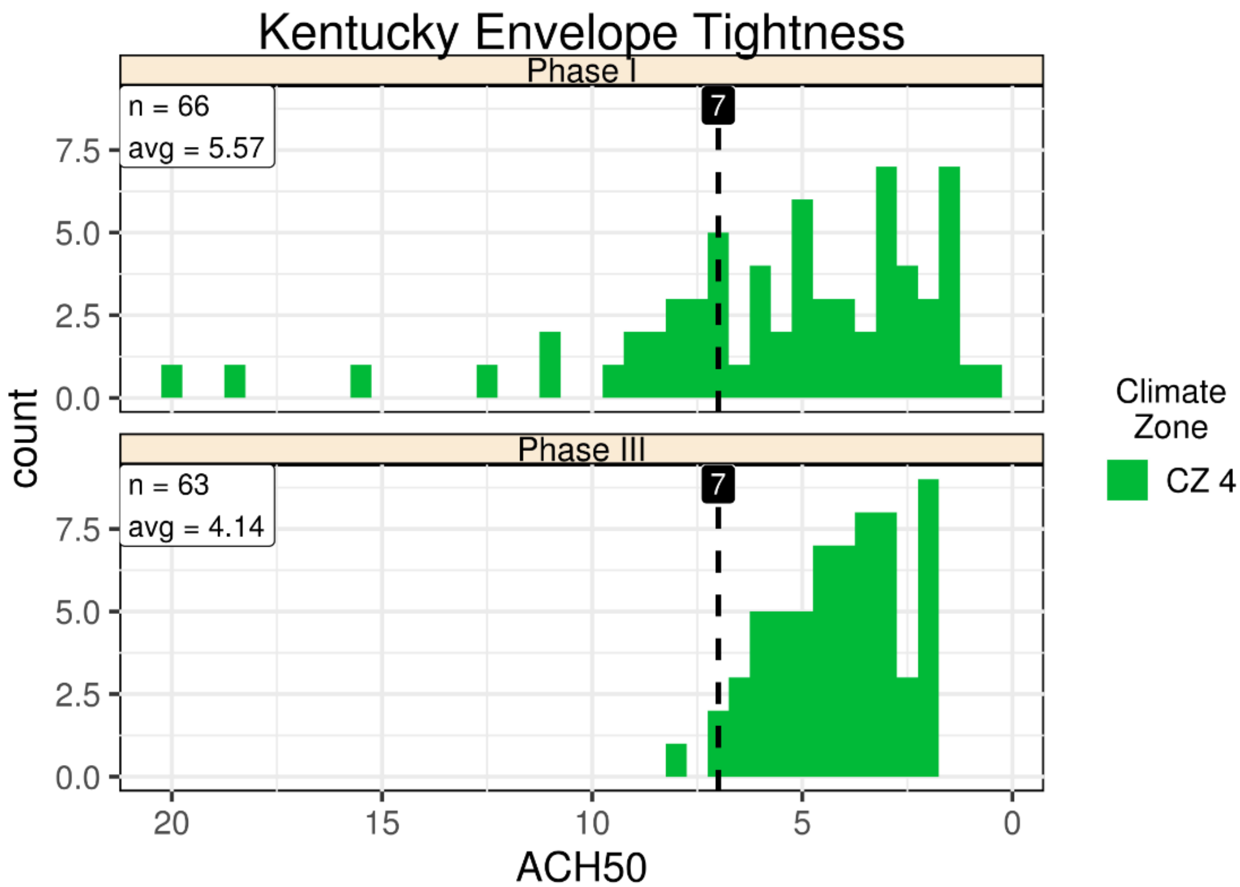

Figure 3.1. Comparison of Phase I and Phase III Envelope Tightness for Kentucky

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

Envelope Tightness (ACH50)	KY Phase I	KY Phase III
Requirement	7 ACH50	7 ACH50
Observations		
Number	66	63
Range	20.00 to 0.51	8.15 to 1.85
Average	5.6	4.1
Compliance Rate	46 of 66 (70%)	61 of 63 (97%)

- **Interpretations**
  - In Phase I, reductions in envelope air tightness represented an area for improvement in the state and was a focus of Phase II education and training activities.
  - The minimum observed envelope tightness increased from 0.51 in Phase I to 1.85 in Phase III; however, the average envelope tightness decreased from 5.6 to 4.1.

– The compliance rate improved from 70% to 97% suggesting the Phase II activities were successful.

3.1.1.2 Window SHGC

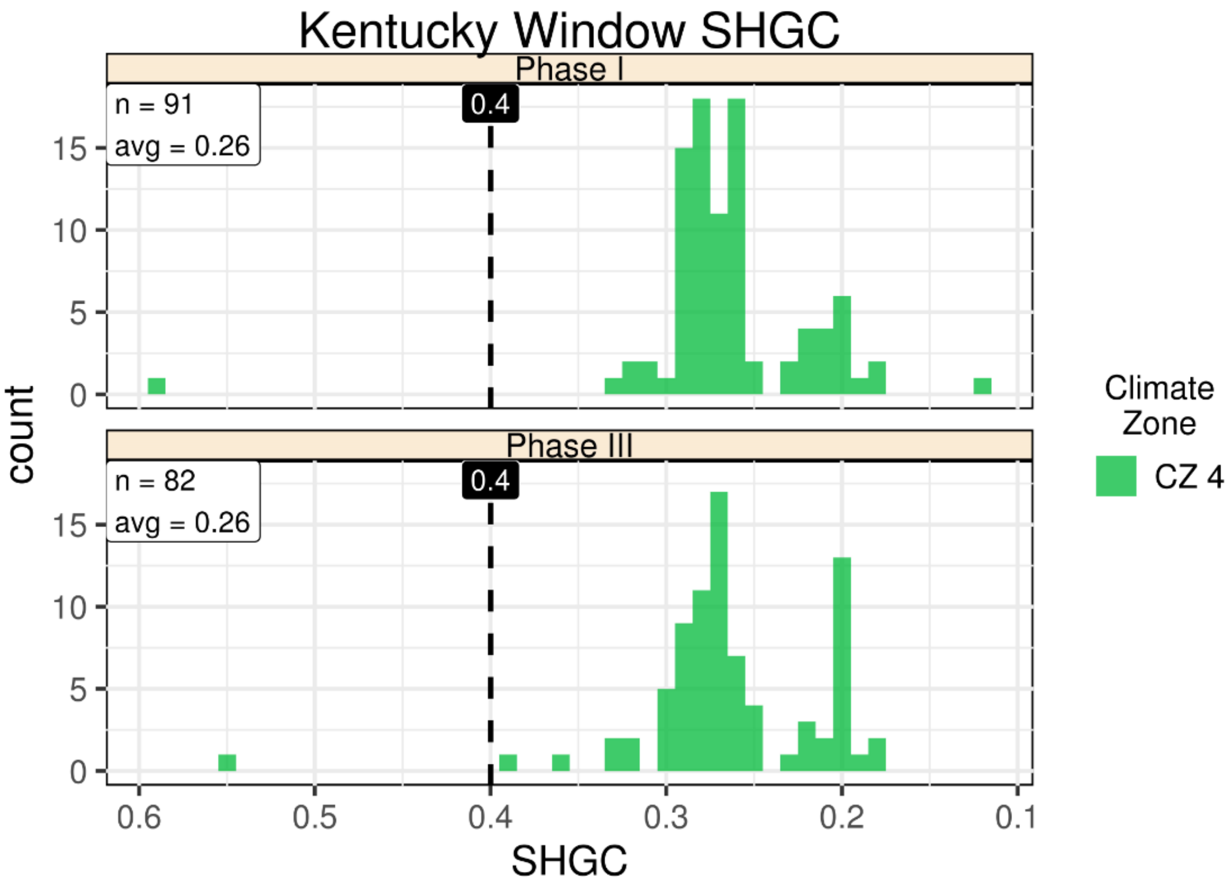

Figure 3.2. Comparison of Phase I and Phase III Window SHGC for Kentucky

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

Window SHGC	KY Phase I	KY Phase III
Requirement	NA	NA
Observations		
Number	91	92
Range	0.59 to 0.12	0.55 to 0.18
Average	0.26	0.26
Compliance Rate	NA	NA

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

3.1.1.3 Window U-Factor

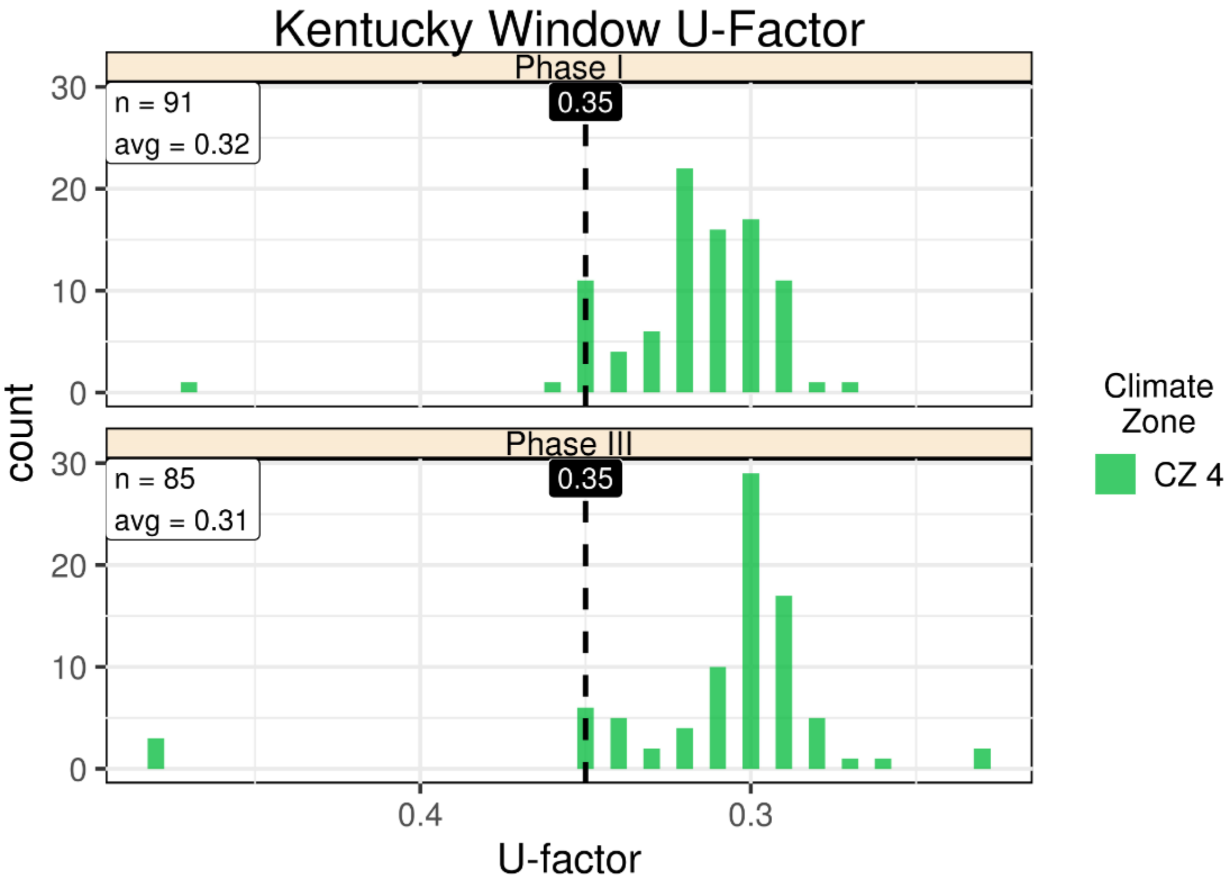

Figure 3.3. Comparison of Phase I and Phase III Window U-Factors for Kentucky

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

Window U	KY Phase I	KY Phase III
Requirement	0.35	0.35
Observations		
Number	91	85
Range	0.49 to 0.27	0.48 to 0.23
Average	0.35	0.31
Compliance Rate	89 of 91 (98%)	82 of 85 (96%)

- **Interpretations:**
  - Although the compliance rate was down slightly in Phase III compared to Phase I, there is a high rate of compliance for fenestration products in the state.
  - This represents one of the most significant findings of the field study, with nearly all of the observations at or above the code requirement.

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.

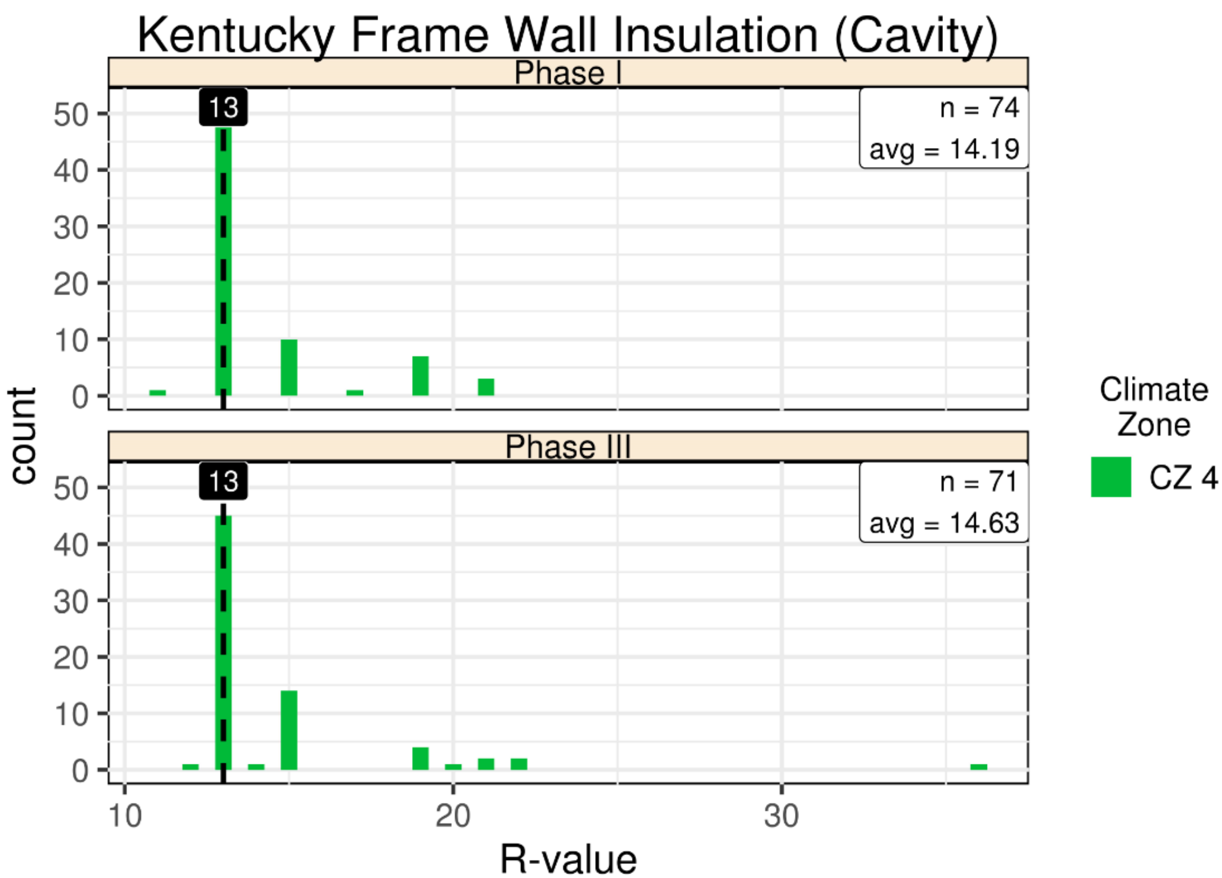

Figure 3.4. Comparison of Phase I and Phase III Wall R-Values for Kentucky

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

Wall R		KY Phase I	KY Phase III
Requirement		R-13	R-13
Observations			
	Number	74	71
	Range	R-11 to R-21	R-12 to R-36
	Average	R-14.2	R-14.6
	Compliance Rate	73 of 74 (99%)	70 of 71 (99%)

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

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

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	25 / 23	37 / 45	9 / 3	**71 / 71**
Above Grade Percentages	35% / 32%	52% / 63%	13% / 4%	**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.

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

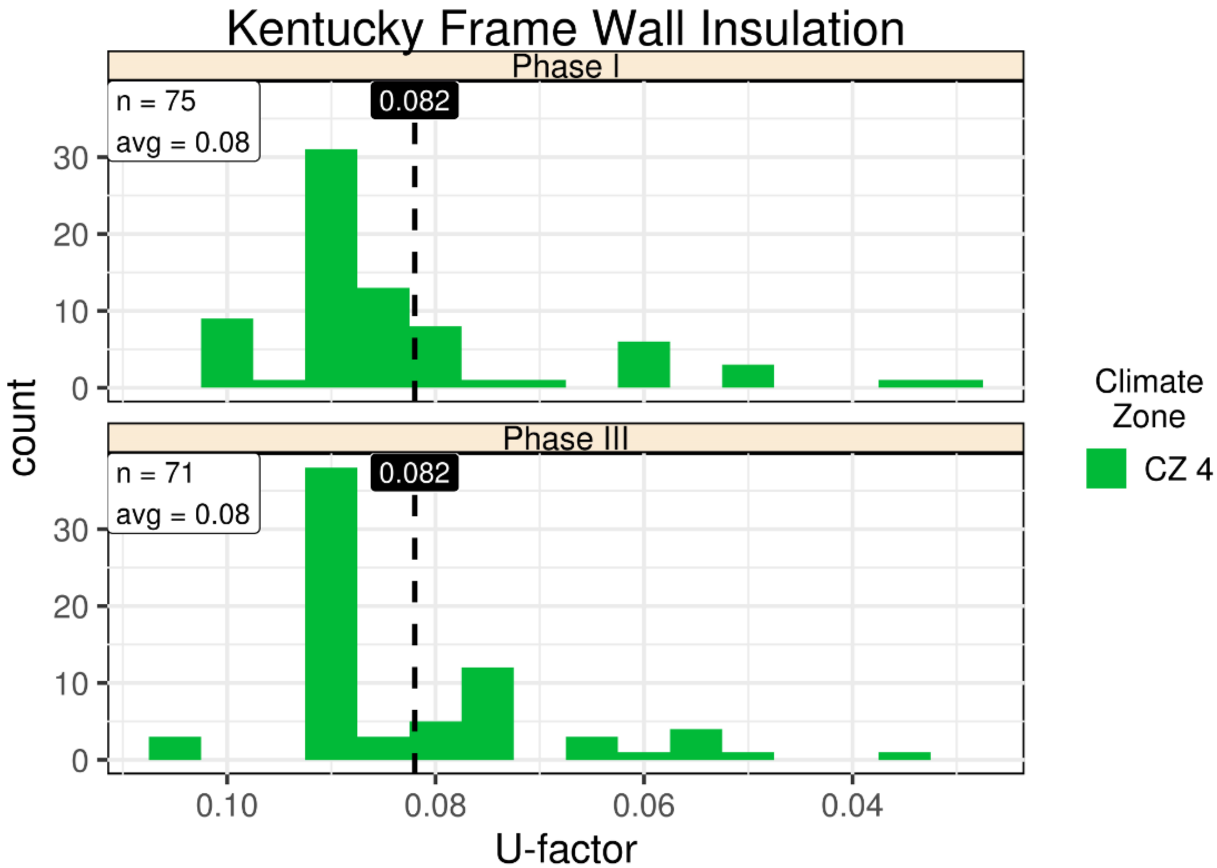

Figure 3.5. Comparison of Phase I and Phase III Wall U-Factors for Kentucky

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

Wall U		KY Phase I	KY Phase III
Requirement		U-0.082	U-0.082
Observations			
	Number	75	71
	Range	U-0.102 to U-0.029	U-0.107 to U-0.035
	Average	U-0.084	U-0.088
	Compliance Rate	21 of 75 (28%)	27 of 71 (38%)

- **Interpretations:**
  - In both Phase I and Phase III, the vast majority of homes were observed to be using R-13 cavity-only insulation. The observations also suggest use of common thicknesses of batt insulation (e.g., R-13, R-15, R-19, etc.).
  - Note that the KY Phase I data shows 74 observations of cavity wall R, while the corresponding U-factor plot shows 75. There are seven walls in Kentucky with both cavity and continuous insulation and one wall with continuous insulation only. The seven walls include the single R-11 observation reported here, which includes R-3 continuous insulation. Judged solely on the amount of insulation installed, all of the Phase I observations in Kentucky would pass and almost

all (99%) of the Phase III observations would pass. There were no walls observed in Phase III with both cavity and continuous insulation.

– Cavity insulation was achieved at a high rate and therefore the amount of wall insulation does not appear to be an issue in the state. However, IIQ is an issue as shown in the lower compliance rates for Wall U-factors compared to Wall R-values. IIQ was a focus of the Phase II education and training activities, but there was only a slight improvement in IIQ and the wall U-factor compliance rate in Phase III, indicating that IIQ is still an issue.

3.1.1.5 Ceiling Insulation

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

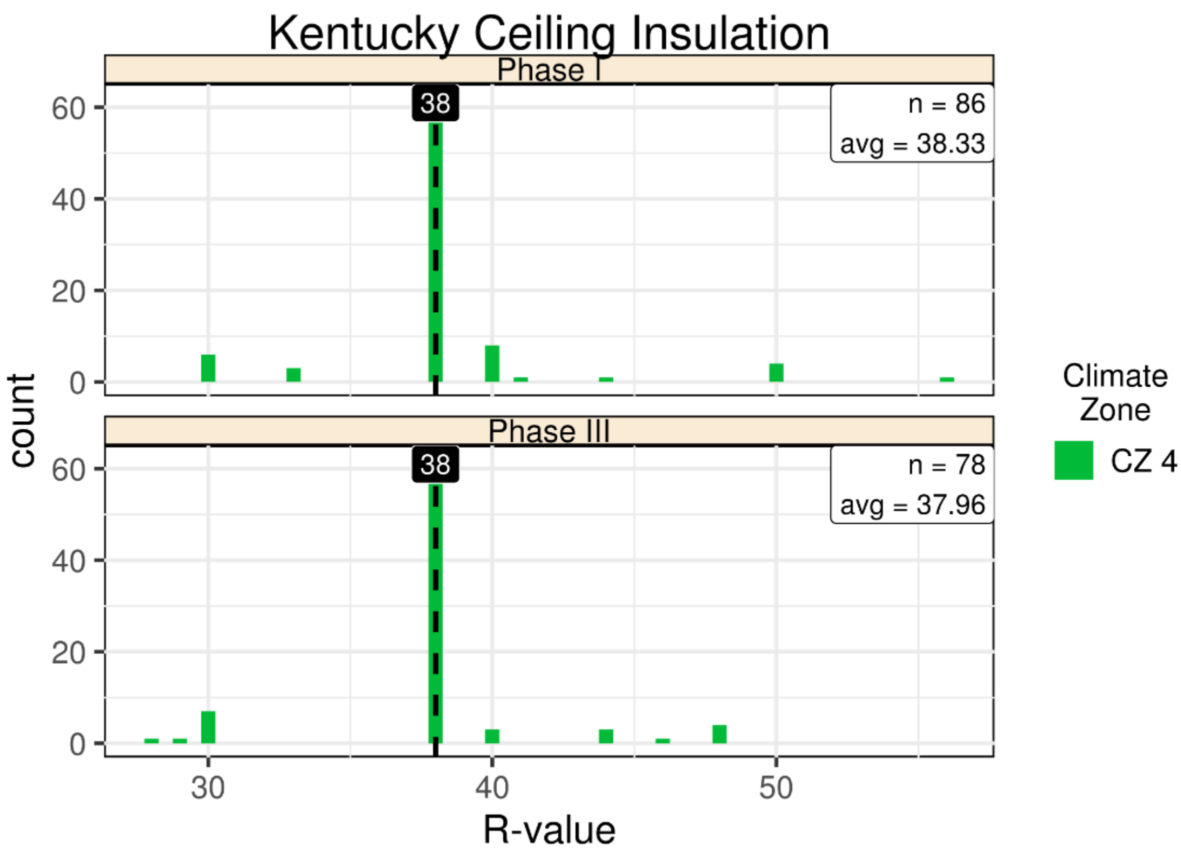

Figure 3.6. Comparison of Phase I and Phase III Ceiling R-Values for Kentucky

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

Ceiling R	KY Phase I	KY Phase III
Requirement	R-38	R-38
Observations		
Number	86	78
Range	R-30 to R-56	R-28 to R-48
Average	R-38	R-38
Compliance Rate	77 of 86 (90%)	69 of 78 (88%)

Table 3.8 shows the number and percentage of IIQ observations by grade for roof cavity insulation for Phase I and Phase III. The table illustrates that roof cavity IIQ improved greatly from Phase I to Phase III, with 75% of the Phase III observations being Grade I.

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

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	34 / 53	47 / 18	5 / 0	**86 / 71**
Roof Cavity Percentages	40% / 75%	55% / 25%	6% / 0%	**100% / 100%**

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

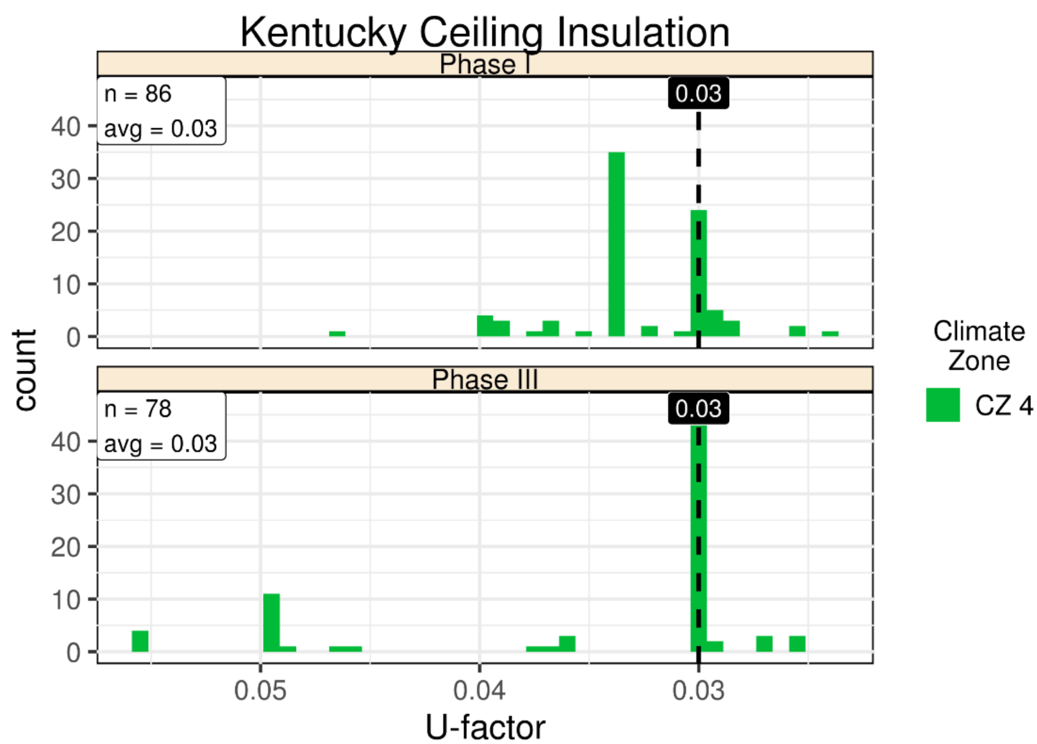

Figure 3.7. Comparison of Phase I and Phase III Ceiling U-Factors for Kentucky

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

Ceiling U	KY Phase I	KY Phase III
Requirement	U-0.03	U-0.03
Observations		
Number	86	78
Range	U-0.024 to U-0.047	U-0.027 to U-0.058
Average	U-0.033	U-0.035
Compliance Rate	35 of 86 (41%)	55 of 78 (71%)

- **Interpretations:**
  - The majority of R-value observations met the code requirement exactly in both Phase I and Phase III.
  - Overall, the amount of ceiling insulation does not appear to be an issue in the state. However, IIQ is an issue as shown in the lower compliance rates for Ceiling U-factors compared to Ceiling R-values. IIQ was a focus of the Phase II education and training activities, and there were considerable improvements in IIQ and Ceiling U-factor compliance in Phase III, however, IIQ is still an issue.

It should be noted the cause of the instances of R-30 in the field is unclear, as R-30 is allowed as an alternative in the 2009 IECC if an energy truss is used. R-30 may also be allowed in cases where there is no room for additional insulation, such as a cathedral ceiling.

3.1.1.6 Lighting

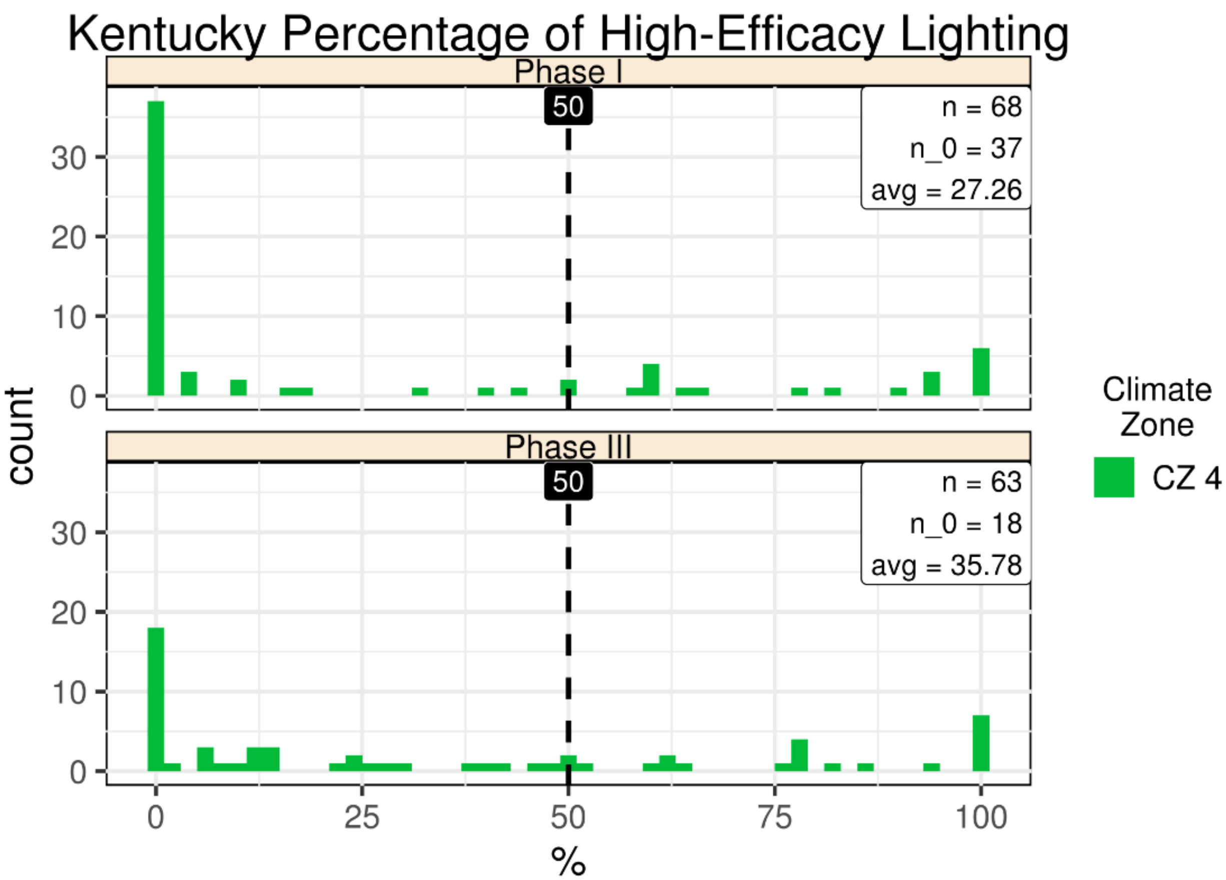

Figure 3.8. Comparison of Phase I and Phase III High-Efficacy Lighting Percentages for Kentucky

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

Lighting	KY Phase I	KY Phase III
Requirement	50%	50%
Observations		
Number	68	63
Range	0 to 100	0 to 100
Average	27	31
Compliance Rate	21 of 68 (31%)	22 of 63 (35%)

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

3.1.1.7 Foundation Assemblies

There were three predominant foundation types observed in Kentucky: conditioned basements, floors, and slabs.[3] Two graphs are shown for basement walls and floors, insulation (R-value) and binned assembly (U-factor). The R-value graphs show the insulation R-values observed. The binned U-factor graphs indicate the U-factor of the assembly, including both cavity and continuous insulation layers, framing, and considering IIQ, as observed in the field. The U-factors are binned to reduce the number of bars in the chart as individual U-factor observations may be only slightly different. For slabs, only an R-value graph is shown.

While initially combined into a single key item (i.e., foundation assemblies[4]), 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 the aggregated individual foundation types (presented later in Section 3.3); however, only the aggregated observations should be considered statistically representative at the statewide level.

[3] While there were many homes noted as having crawlspaces, only 4 observations of crawlspace wall insulation were made in Phase I, and only 8 observations in Phase III. For this reason, crawlspace wall insulation was not included as key item or as a measure level savings item for Phase I in Section 3.3.
[4] Floor insulation, basement wall insulation, crawlspace wall insulation (for Phase III only), and slab insulation were combined into a single key item of foundation insulation.

Basement Walls

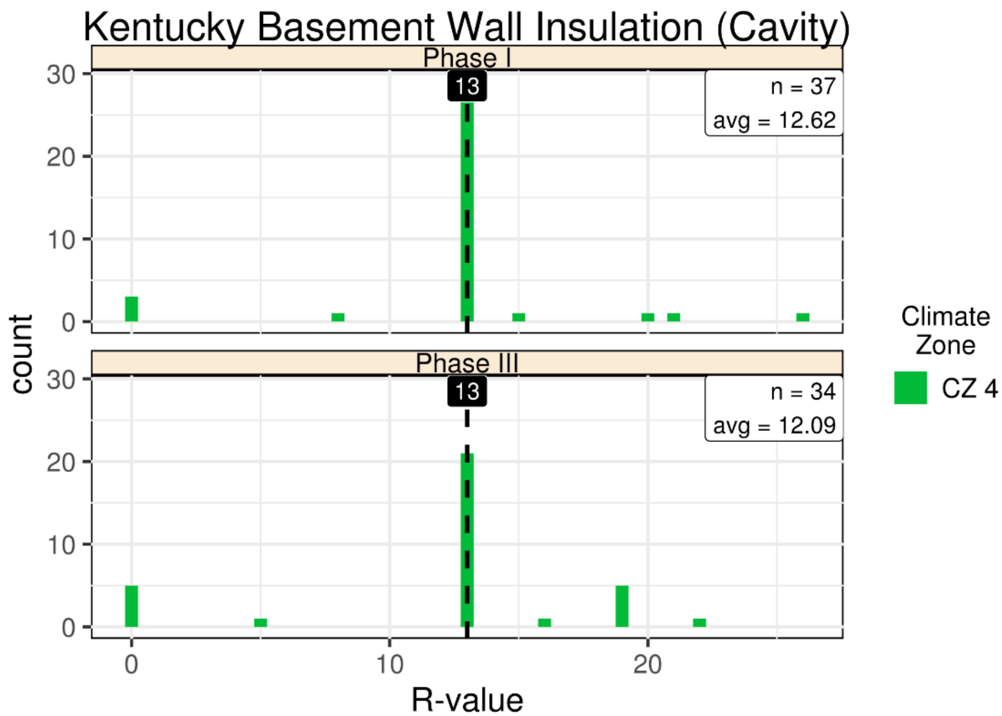

Figure 3.9. Comparison of Phase I and Phase III Basement Wall Cavity R-Values for Kentucky

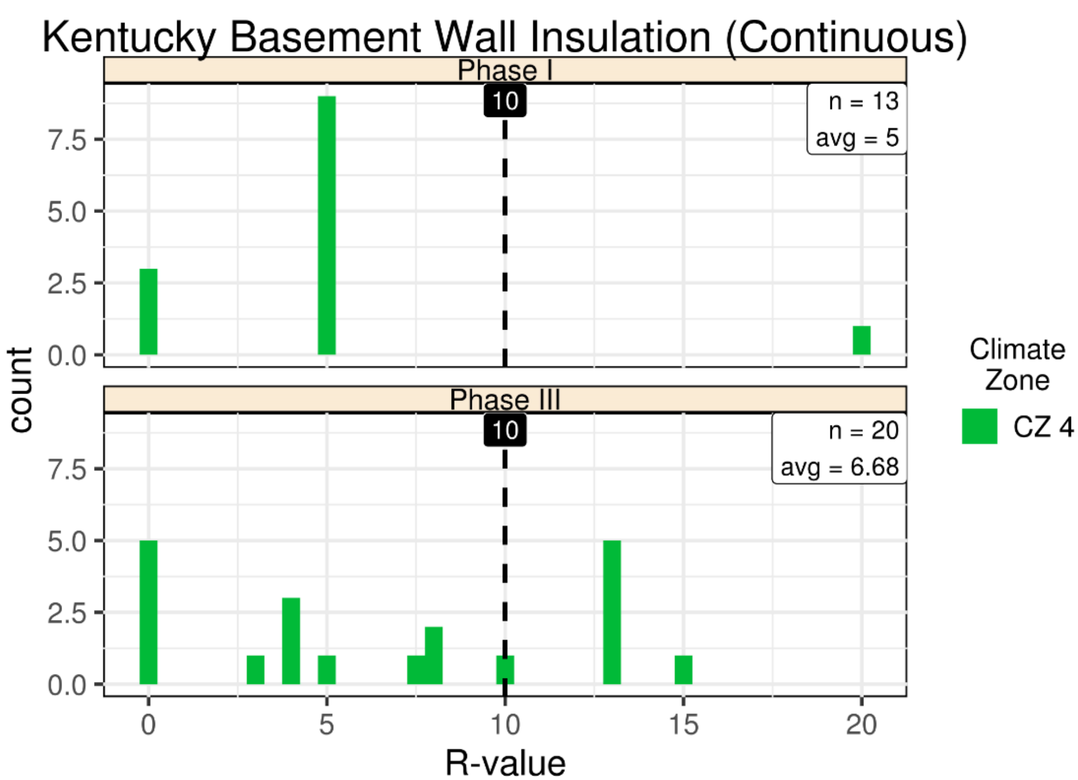

Figure 3.10. Comparison of Phase I and Phase III Basement Wall Continuous R-Values for Kentucky

Table 3.11 shows the number and percentage of IIQ observations by grade for basement wall insulation for Phase I and Phase III. Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.11.

Table 3.11. Basement Wall IIQ Comparison between Phase I and Phase III for Kentucky

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Basement Wall Observations	5 / 4	23 / 29	2 / 1	**30 / 34**
Basement Wall Percentages	17% / 12%	77% / 85%	7% / 3%	**100% / 100%**

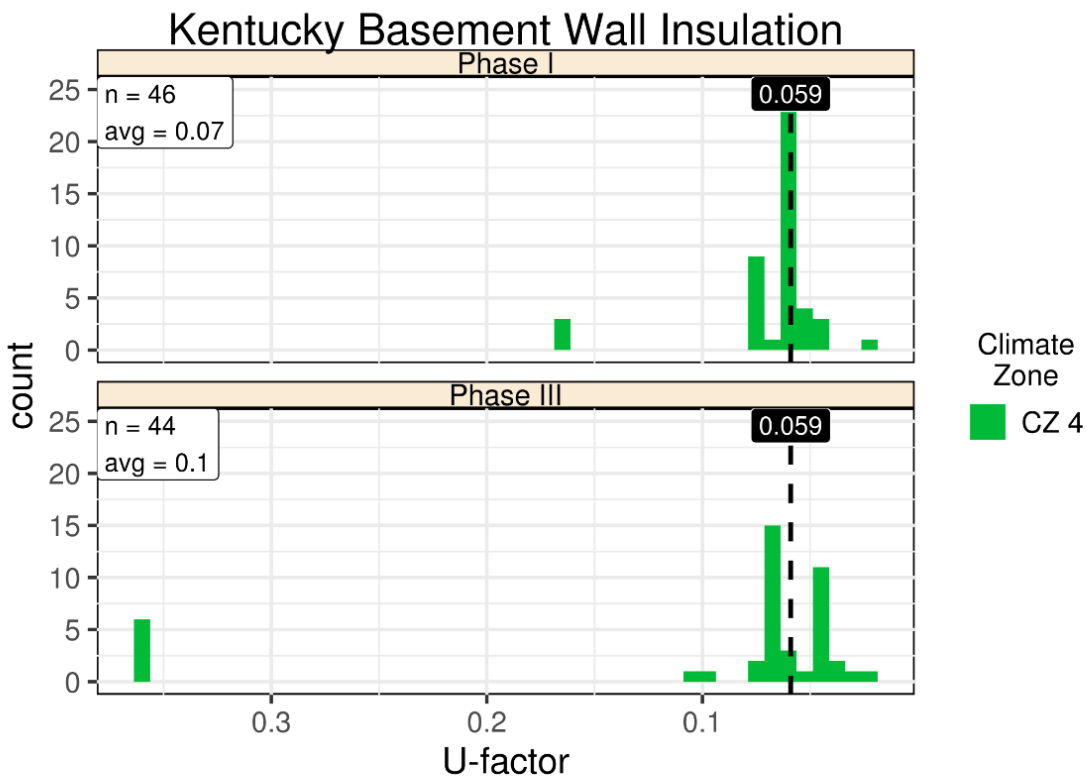

Figure 3.11. Comparison of Phase I and Phase III Basement Wall U-Factors for Kentucky

Table 3.12. Kentucky Basement Wall U-Factors in Phase I and Phase III

Basement Wall U	KY Phase I	KY Phase III
Requirement	U-0.059	U-0.059
Observations		
Number	46	44
Range	U-0.163 to U-0.026	U-0.036 to U-0.04
Average	U-0.068	U-0.099
Compliance Rate	8 of 46 (18%)	26 of 44 (59%)

- **Interpretations:**
  - The R-value graph indicates that no basement walls with continuous insulation met the requirement (12 observations) in Phase I, while the majority of basement walls with either cavity insulation or a combination of cavity and continuous insulation (34 observations) did, indicating that the amount of insulation is the issue for basement walls with only continuous insulation.
  - The U-factor graph indicates a large number of observations (38) that did not meet the requirement in Phase I. The majority of these observations (23) have R-13 cavity insulation with Grade II or Grade III IIQ, indicating IIQ is an issue for basement walls.
  - The average basement wall U increased in Phase III (not good), but the compliance rate went up significantly (good), indicating a fairly major change in the distribution of basement wall U-factors. There appear to be two issues – there are more uninsulated basement walls in Phase III and there also appears to be a number of walls that just fail to meet the U-factor requirement, indicating that the proper amount of insulation was installed, but the IIQ was not Grade I.
  - The majority of insulation installation quality observations in Phase III were Grade II. Although there was some improvement in Phase III, basement wall IIQ is still an issue.

Floors

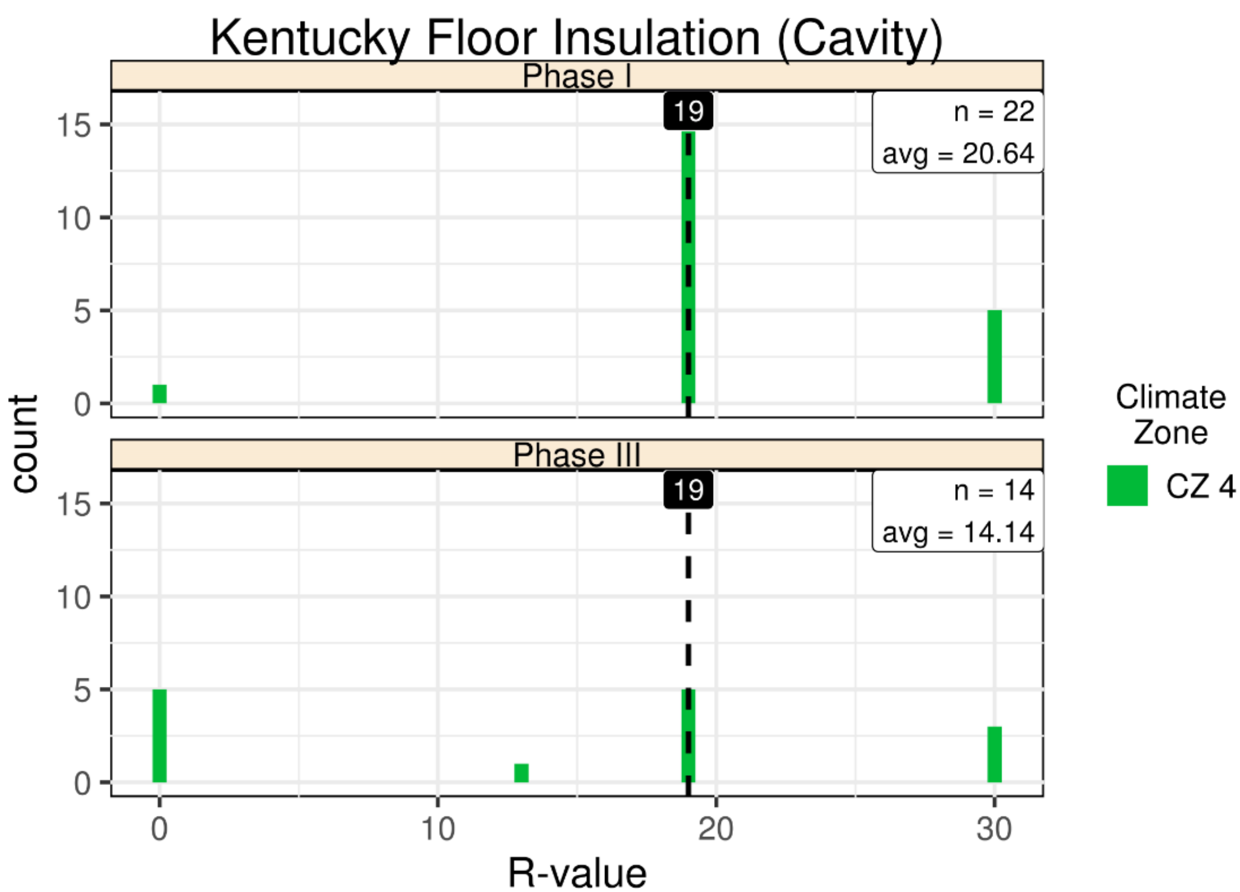

Figure 3.12. Comparison of Phase I and Phase III Floor R-Values for Kentucky

Table 3.13 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 declined from Phase I to Phase III. Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.13.

Table 3.13. Floor IIQ Comparison between Phase I and Phase III for Kentucky

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	8 / 0	10 / 14	2 / 3	**20 / 17**
Floor Percentages	40% / 0%	50% / 82%	10% / 18%	**100% / 100%**

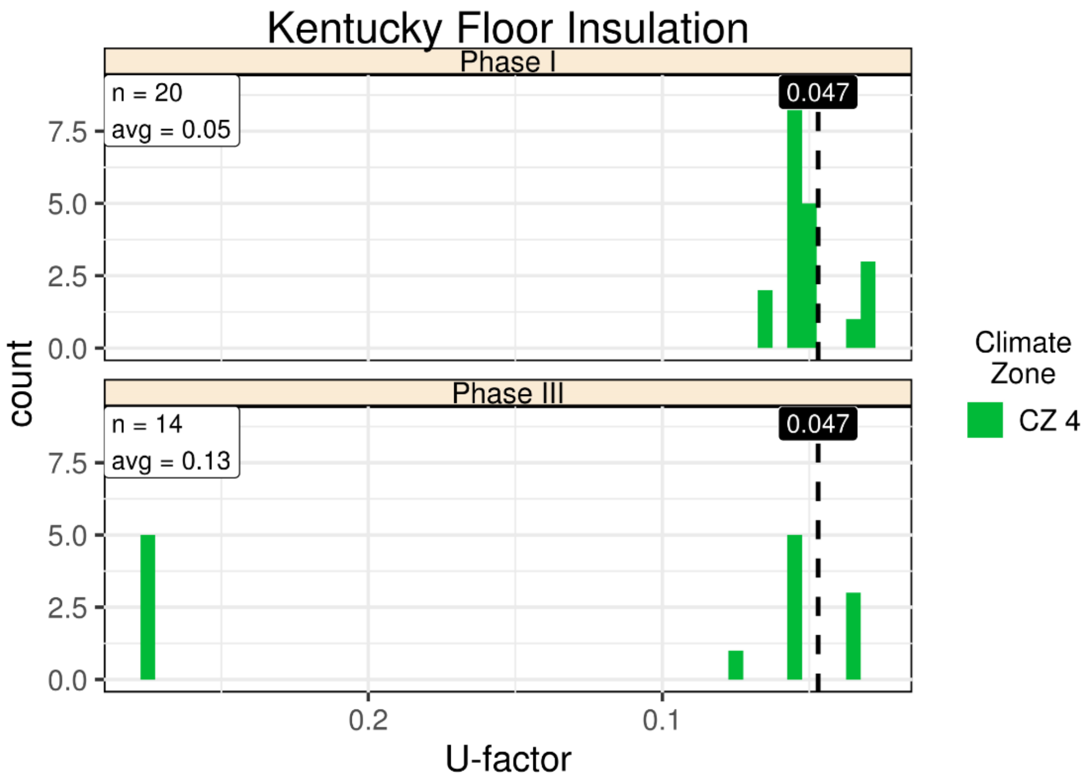

Figure 3.13. Comparison of Phase I and Phase III Floor U-Factors for Kentucky

Table 3.14. Kentucky Floor U-Factors in Phase I and Phase III

Floor U	KY Phase I	KY Phase III
Requirement	U-0.047	U-0.047
Observations		
Number	20	14
Range	U-0.064 to U-0.032	U-0.041 to U-0.391
Average	U-0.050	U-0.13
Compliance Rate	4 of 20 (20%)	3 of 14 (21%)

- **Interpretations:**
  - Cavity insulation was achieved at a high rate in Phase I—most observed instances met or exceeded the prescriptive code requirement (based on labeled R-value).
  - From an assembly perspective, a majority of observations had Grade II or Grade III IIQ in both Phase I and Phase III.
  - While cavity insulation levels appear to be achieved successfully (R-value) in Phase I, the overall assembly performance (U-factor) exhibited room for improvement and was a focal point for Phase II education and training activities.
  - In Phase III, cavity insulation is achieved at a lower rate and the average U-factor increased from 0.05 in Phase I to 0.13 in Phase III, indicating a deterioration in floor insulation.

Slabs

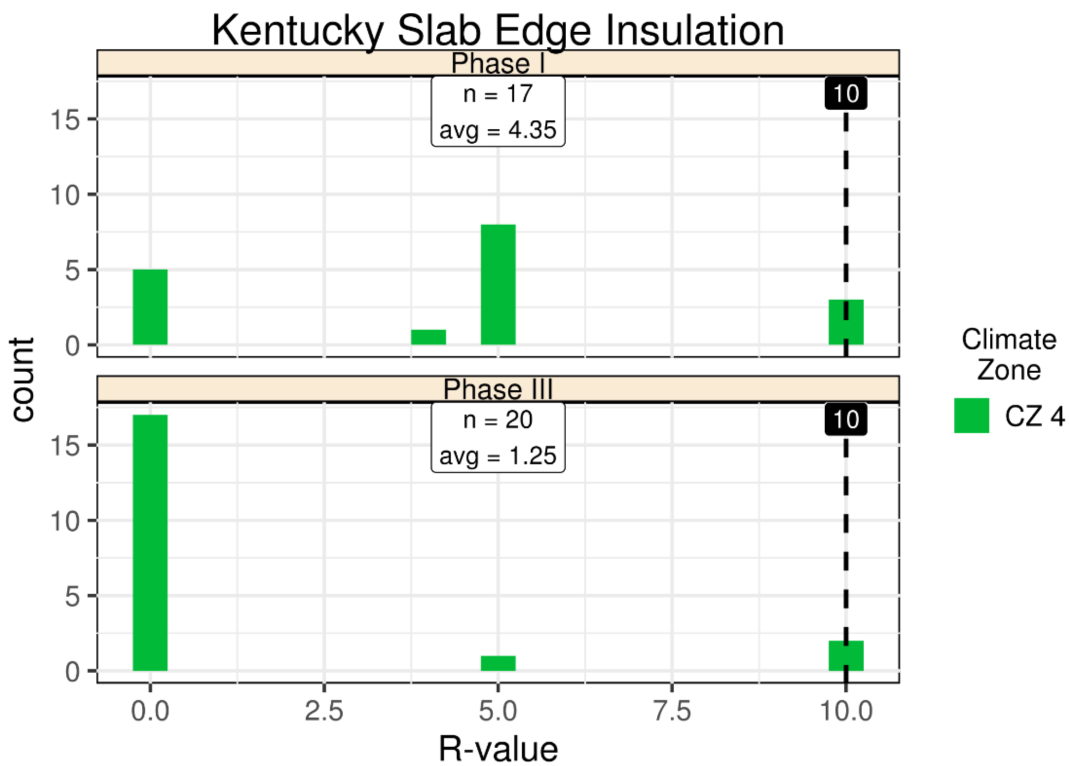

Figure 3.14. Comparison of Phase I and Phase III Slab R-Values for Kentucky

Table 3.15. Kentucky Slab R-Values in Phase I and Phase III

Slab R	KY Phase I	KY Phase III
Requirement	10	10
Observations		
Number	16	20
Range	R-0 to R-10	R-0 to R-10
Average	R-4	R-1.25
Compliance Rate	2 of 10 (20%)	2 of 20 (10%)

- **Interpretations:**
  - The majority of slab edge insulation observations did not comply (80%) in Phase I, including several observations of no slab insulation. Slab insulation was a focal point of Phase II education and training activities.
  - Average slab insulation decreased and the compliance rate dropped in half to 10% in Phase III indicating that slab insulation continues to be an issue.

Crawlspace Walls

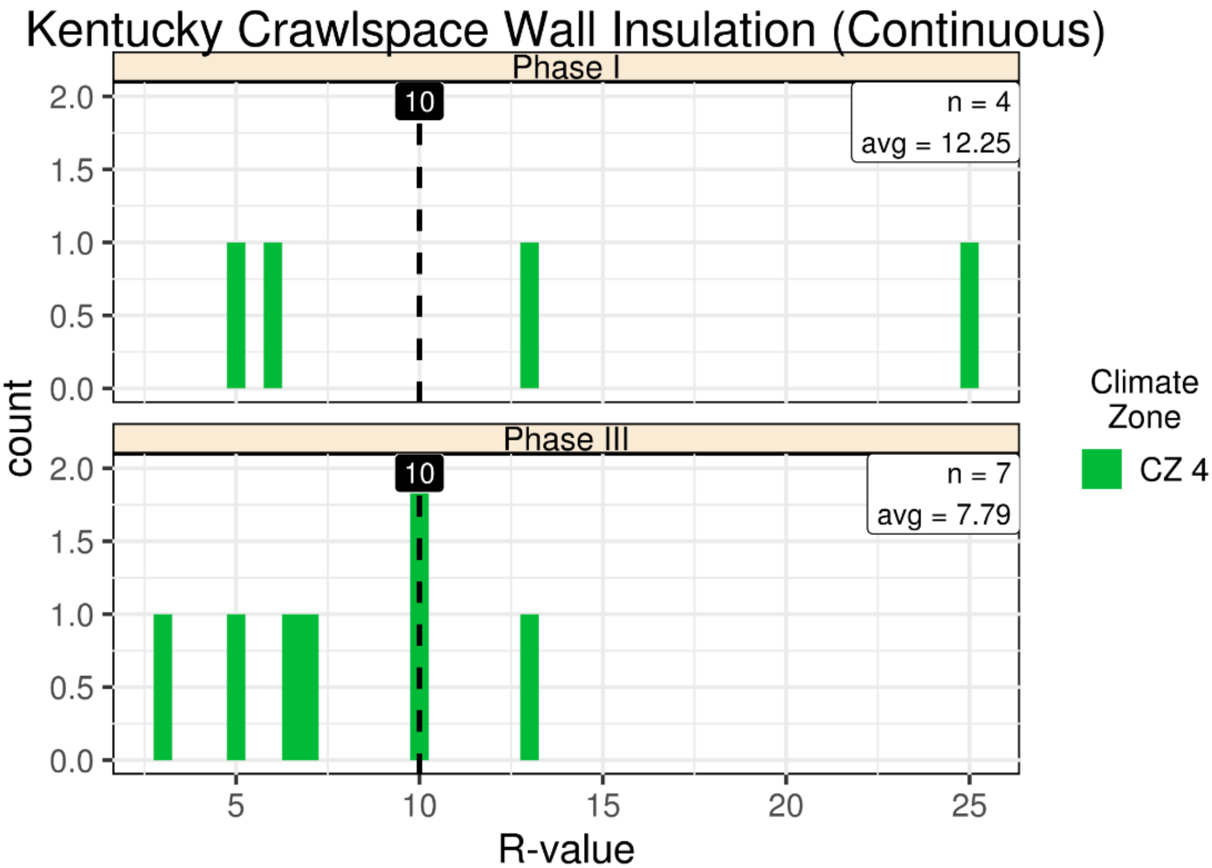

Figure 3.15. Phase III Crawlspace Wall R-values for Kentucky

Table 3.16. Kentucky Crawlspace Wall R-values in Phase III

Crawlspace Wall R	KY Phase I*	KY Phase III
Requirement	10 (continuous)	10 (continuous)/13 (cavity)
Observations		
Number	4	8
Range	R-6 to R-25	R-0 to R-13
Average	R-12.25	R-6.81
Compliance Rate	2 of 4 (50%)	3 of 8 (38%)

*KY Phase I crawlspace data not previously reported due to the small number of observations.

There were no observations of cavity crawlspace wall insulation installation quality in either Phase I or Phase III. Note in Phase III there were 7 crawlspace wall observations with continuous insulation and 1 observation with R-0 cavity insulation. No R-value graphic is shown to represent the 1 observation of R-0, but that observation is included in the U-factor graphic for a total of 8 observations.

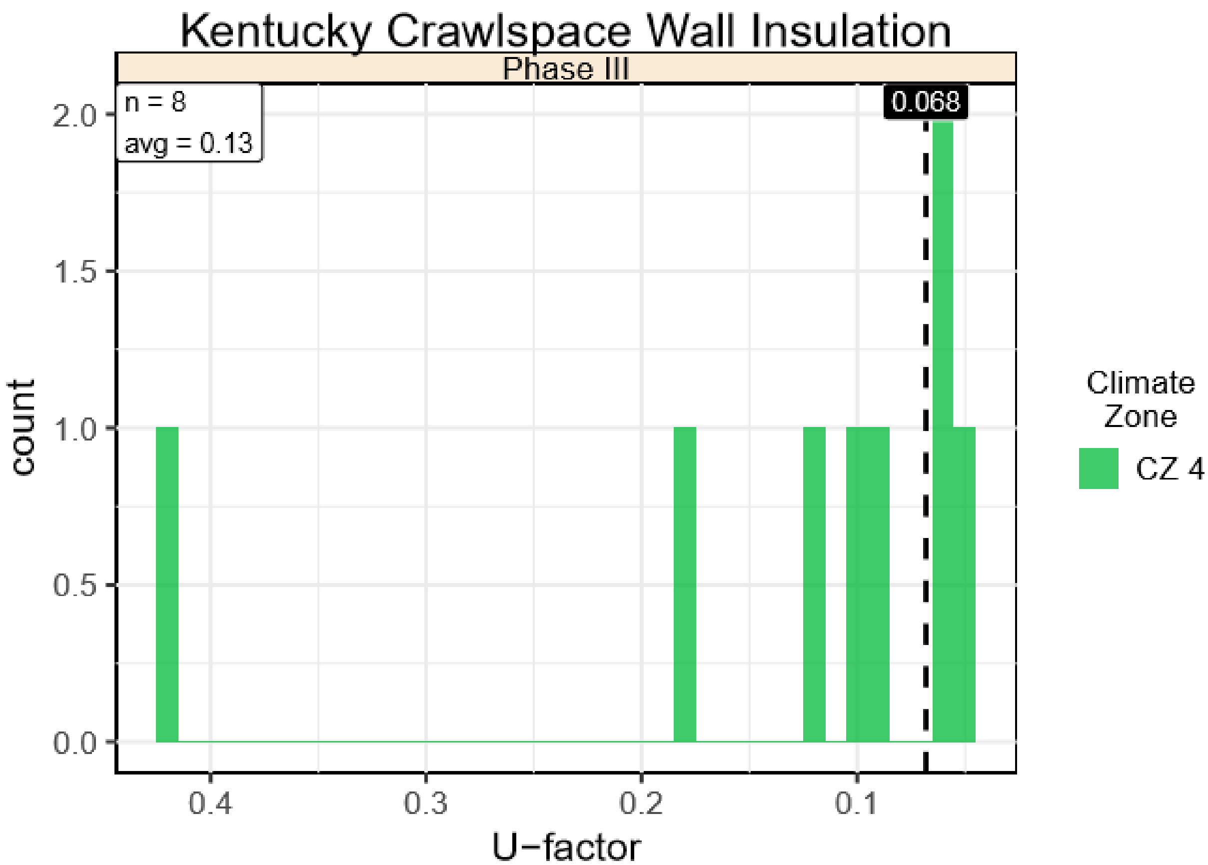

Figure 3.16. Phase III Crawlspace Wall U-Factors for Kentucky

Table 3.17. Kentucky Crawlspace Wall U-Factors

Crawlspace Wall U	**KY Phase I****	**KY Phase III**
Requirement	U-0.068	U-0.068
Observations		
Number	4	8
Range	~U-0.040 to U-0.101	U-0.055 to U-0.233
Average	~U-0.072	U-0.103
Compliance Rate	2 of 4 (50%)	3 of 8 (38%)

**KY Phase I crawlspace data not previously reported due to small number of observations. Some U-factors approximated.

- Interpretations
  - There is a considerable range of values reported for crawlspace wall U-factor in Phase I due in large part to one wall reported to have R-25 continuous insulation.

- There is an even greater range of U-factors observed in Phase III, due largely to a single observation of R-0 cavity insulation leading to a high U-factor of 0.233.
- The percentage of observations that comply decreased from Phase I to Phase III, but the small sample sizes preclude placing much significance on this.

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 tightness observed in the field. Adjusted duct tightness looks at the location of the ducts and adjusts the leakage values for any ducts which are entirely in conditioned space by setting the leakage of those ducts to zero (0). The adjustment reflects the fact that duct tightness tests are not required if the ducts are entirely in conditioned space.

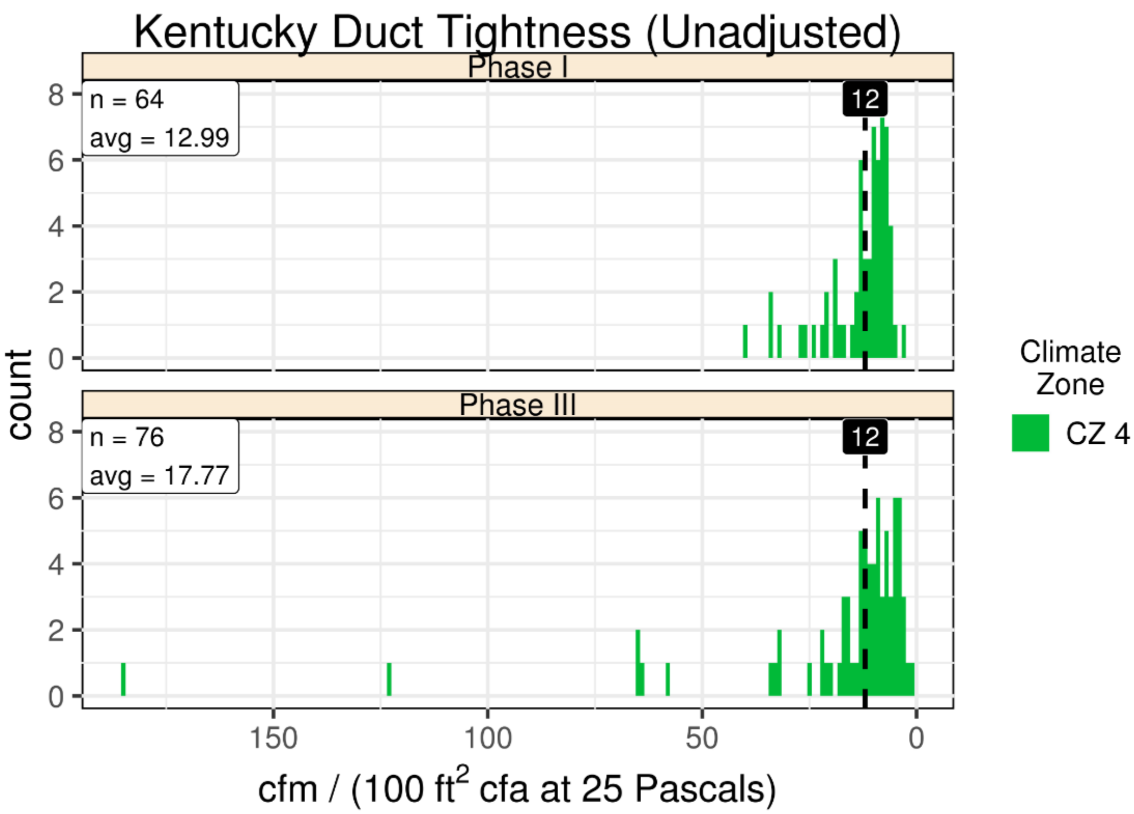

Figure 3.17. Comparison of Phase I and Phase III Duct Tightness Values for Kentucky

Table 3.18. Kentucky Duct Tightness Values in Phase I and Phase III (unadjusted)

Duct Tightness	KY Phase I	KY Phase III
Requirement	12	12
Observations		
Number	64 total (40 with ducts not entirely in conditioned space)	76 total (52 with ducts not entirely in conditioned space)
Range	40.4 to 3.1	185 to 1.1

Average	9.7 in unconditioned space, 18.5 for ducts 100% in conditioned space	15.1 in unconditioned space, 23.5 for ducts 100% in conditioned space
Compliance Rate	39 of 64 (61%), 31 of 40 (77%) for ducts not entirely in conditioned space	57 of 76 (75%), 33 of 52 (63%) for ducts not entirely in conditioned space

- **Interpretations:**
  - Overall the distribution of Phase I observations exhibits higher leakage than expected compared to the current code requirement. There was also a large range of results.
  - Just over 60% of all Phase I observations met the prescriptive requirement, with an average leakage of 12.99 CFM25/100 ft2 CFA. However, 16 of the 25 observations that failed are for ducts that are 100% in conditioned space.[5] When looking only at ducts that are not entirely in conditioned space, 77% of the observations meet the prescriptive requirement.
  - Reductions in duct leakage (to unconditioned space) was a focal point of Phase II education and training activities.
  - Duct leakage increased both for ducts entirely in conditioned space and for ducts not in conditioned space in Phase III. The increase for ducts not in conditioned space leads to increased measure-level savings for duct leakage and an increased observed EUI for Phase III.
  - Overall, the compliance rate went up because there were more ducts installed in conditioned space, but the compliance rate for ducts not entirely in conditioned space decreased.

3.1.2 Additional Data Items

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

The following represents a summary of this data and outlines some of the more significant findings, in many cases including the observation or compliance rate associated with the specified item. A larger selection of the additional data items collected as part of the Kentucky field study is contained in Appendix C. The full data set is also available on the DOE Building Energy Codes Program website.[6]

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

[5] There were 25 homes with ducts located entirely within conditioned space in Phase I, and these ducts exhibit higher leakage. There were 64 duct systems located entirely within conditioned space in Phase III and as in Phase I, these ducts tended to exhibit higher leakage. Leakage from ducts that are located entirely within conditioned space is not considered to be an issue in energy codes and these leakage rates were not included in the energy analysis.
[6] Available at https://www.energycodes.gov/compliance/energy-code-field-studies.

3.1.2.1 Average Home

Table 3.19. Average Home

Home Statistics	Phase I	Phase III
Average square footage (ft^2)	2400	2900[7]
Number of Stories	1.3	1.6

3.1.2.2 Compliance

All homes were permitted under the 2009 IECC (100%) in both Phase I and Phase III.

3.1.2.3 Envelope

Table 3.20. Envelope

Requirement	Phase I	Phase III
Profile		
Walls	Majority wood-framed with mix of 4” (88%), 6” (10%), and 2” (1%) (n=138)	Majority wood-framed with mix of 4” (89%) and 6” (11%) (n=115)
Foundations	n=140	n=128
Basement	41%	47%
Slab-on-grade	35%	27%
Crawl space	24%	27%
Insulation labeled	85% (n=85)	95% (n=55)
Lighting fixtures sealed	100% (n=65)	93% (n=76)
Utility penetrations sealed	81% (n=95)	67% (n=70)
Attic hatches and doors complied	40% (n=55)	17% (n=48)
Attic access openings sealed	41% (n=54)	47% (n=53)

3.1.2.4 Duct & Piping Systems

Table 3.21. Duct and Piping Systems

Requirement	Phase I	Phase III
Profile		
Supply ducts located within conditioned space (percentage of duct system)	48% (n=133)	36% (n=187)

[7] Based on random sampling, several large homes were included in Phase III. See Table C.2 in Appendix C for additional data on square footage ranges.

Requirement	Phase I	Phase III
Return ducts located within conditioned space (percentage of duct system)	51% (n=133)	59% (n=196)
Supply ducts entirely within conditioned space (percentage of homes and number)	40% (53 homes)	53% (44 homes)
Return ducts entirely within conditioned space (percentage of homes and number)	41% (55 homes)	53% (45 homes)
Duct Insulation	R-7.3 (n=165)	R-7.2 (n=190)
Pipe Insulation	R-2.4 (n=105)	R-3 (n=106)
Building cavities not used as supply ducts	96% (n=98)	93% (n=102)
Air handlers sealed	87% (n=110)	96% (n=105)
Filter boxes sealed	85% (n=100)	86% (n=95)

Successes and Improvement

As a percentage of compliant observations, successes include insulation labeling, sealing of lighting fixtures and utility penetrations, and building cavities not being used as supply ducts. Areas identified for improvement in Phase I, air handlers sealed and filter boxes sealed, improved in Phase III. Air handlers went from 13% compliant observations to 96%, and filter boxes improved to 86% in Phase III from 5%. Areas that could still use improvement include attic hatches and doors and attic openings.

3.1.2.5 HVAC Equipment

Table 3.22. HVAC Equipment

Requirement	Phase I	Phase III
Profile		
Heating equipment type	Split evenly between gas furnaces and heat pumps (n=114, 50 gas furnace, 54 electric heat pump, 9 electric furnace, 1 electric resistance strip heat)	Split evenly between electric furnaces and heat pumps (n=125, 64 gas furnace, 59 electric heat pump, and 2 electric furnace)
Heating equipment efficiency	88 AFUE furnace, 8.2 HSPF heat pump (n=81 total)	89 AFUE furnace, 8.2 HSPF heat pump (n=97 total)
Cooling equipment type	Majority heat pumps (n=90,62 heat pump, 28 central AC)	Majority heat pumps (n=87, 50 heat pump, 36 central AC, 1 room AC)
Cooling equipment efficiency	13 SEER	14.1 SEER
Water heating equipment type	Mostly electric storage (n=83, 55 electric storage, 12 gas storage, 12 gas tankless, 2 electricity heat pump storage, 1 electricity tankless, and 1 wood storage)	Mostly electric storage (n=92, 53 electric storage, 26 gas storage, 11 gas tankless, 2 electricity heat pump storage)

Water heating equipment capacity	84 gallons (n=65)	53 gallons (n=60)[8]
Water heating equipment efficiency	EF 0.90 (n=25, value is for all reported EF below 1)	EF 0.87 (n=57, value includes 1 heat pump water heater at EF-3.24)

Successes

User manuals were provided 84% of the time in Phase I, but 100% of the time in Phase III.

3.2 Energy Use Intensity

The statewide energy analysis results in Figure 3.18 show the study was successful, with a measurable decrease in statewide EUI between Phase I and Phase III. The change in EUI of 1.82 $kBtu/ft^2$ is greater than 1.25 $kBtu/ft^2$ and is therefore considered statistically significant. The observed data set (as gathered in the field) was compared against the same set of homes meeting prescriptive code requirements. The average energy consumption went down by over 5%. Table 3.23 compares the Phase I and Phase III results.

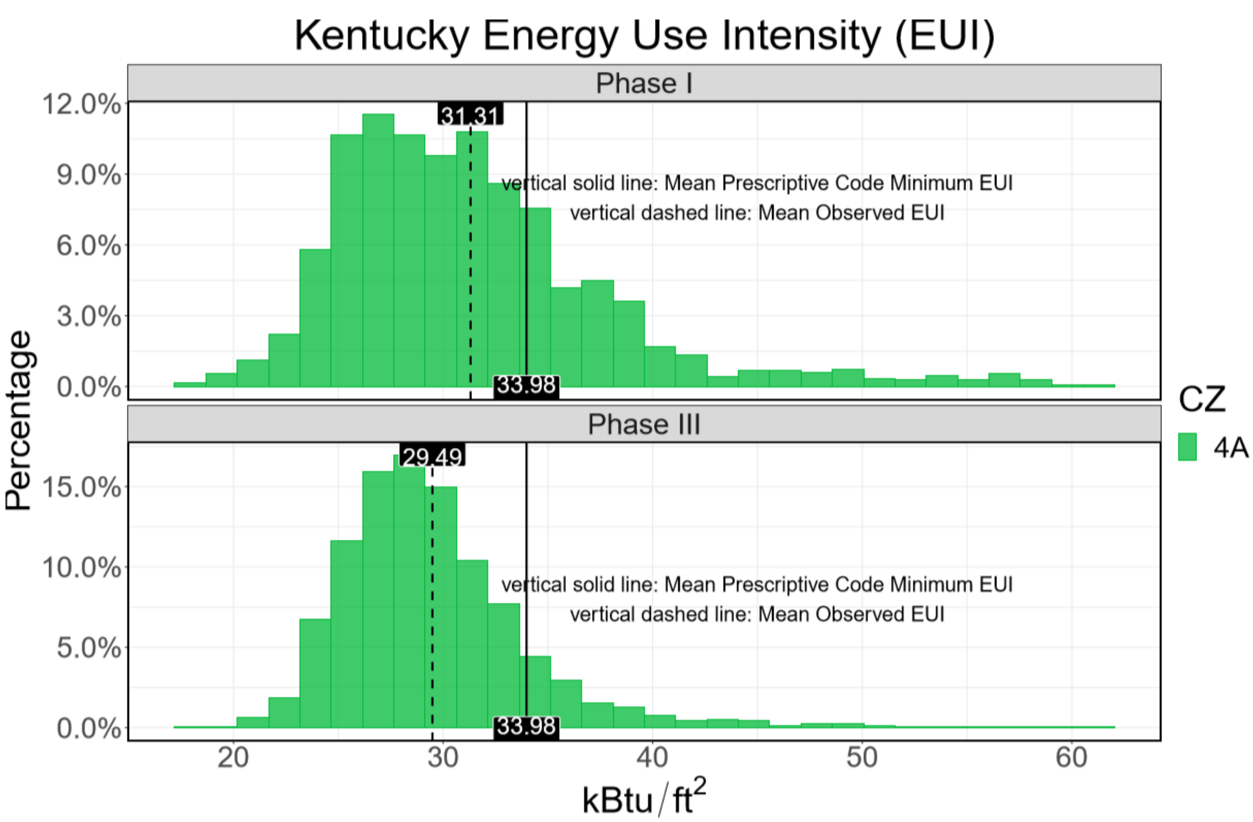

Figure 3.18. Comparison of Phase I and Phase III Statewide EUI for Kentucky

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

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

Phase I EUI Observed / Code (kBtu/ft^2)	Phase III EUI Observed / Code (kBtu/ft^2)	Percentage Difference from Code Phase I / Phase III	Percentage Difference between Phase I and Phase III
31.31 / 33.98	29.49 / 33.98	-7.9% / -13.2%	-5.8%

3.3 Savings Potential

Several key items in Phase I were previously identified as exhibiting the potential for improvement. Those with the greatest potential[9], shown below followed by the percent that met code, were analyzed further to calculate the associated savings potential, including energy, cost and carbon savings.

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

Measure	Phase I Compliance Rate	Phase III Compliance Rate	Phase III to Phase I Difference in Compliance Rate
Envelope Air Tightness[10]	70%	97%	+27%
Ceiling Insulation	59%	71%	+12%
Exterior Wall Insulation	28%	38%	+10%
Basement Wall Insulation	67%	59%	-8%
Floor Insulation	45%	21%	-24%
Slab Insulation	20%	10%	-10%
Crawlspace Wall Insulation[11]	NA	38%	NA
Lighting	31%	35%	+4%
Duct Tightness[12]	77%	63%	-14%

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

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

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

[10] Envelope air tightness had a high enough compliance percentage in Phase III to not be listed, but is included here for comparison.

[11] Crawlspace wall insulation had too few observations in Phase I (4) to be considered. Of the 4 observations, there was a 50% compliance rate. Given that it was not reported in Phase I, a direct comparison is not applicable.

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

Table 3.25. 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
Envelope Air Tightness	27,182	581	484,314	10,321	3,092	65
Ceiling Insulation	11,372	4,835	215,656	91,786	1,080	595
Exterior Wall Insulation	9,277	8,243	171,044	151,974	1,102	976
Foundation Insulation	6,800	11,676	108,156	178,905	668	1075
Lighting	5,742	4,454	197,544	153,383	1,427	1130
Duct Tightness	2,135	17,151	43,142	342,217	284	2251
TOTAL	**62,508 MMBtu**	**46,941 MMBtu**	**$1,219,856**	**$928,585**	**7,653 MT CO2e**	**6,093 MT C02e**

On an individual measure basis, the Phase II education and training activities were successful in reducing the savings potential for most measures and especially for envelope air tightness and ceiling insulation. The measure-level energy cost savings for envelope air tightness showed a reduction of 98%, while ceiling insulation showed a reduction of 57%.

Two measures, foundation insulation and duct tightness, were not as successful, with savings increasing across all three metrics. However, overall energy cost measure-level savings showed a 24% reduction between Phase I and Phase III. Potential annual savings accumulate over time. Table 3.26 compares energy cost savings between Phase I and Phase III accumulated over 5, 10, and 30 years of construction. For additional details on electricity savings and natural gas savings per home associated with each measure; savings by individual foundation components; and how the total savings and emissions reductions accumulate over 5, 10, and 30 years of construction in each phase, see Appendix D.

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

Measure	Potential Total Energy Cost Savings ($) 5 yr		Potential Total Energy Cost Savings ($) 10 yr		Potential Total Energy Cost Savings ($) 30 yr	
	Phase I	Phase III	Phase I	Phase III	Phase I	Phase III
Envelope Air Tightness	7,264,710	154,808	26,637,270	567,628	225,206,010	4,799,034
Ceiling Insulation	3,234,844	1,376,788	11,861,095	5,048,222	100,280,170	42,680,420
Exterior Wall Insulation	2,565,660	2,279,606	9,407,420	8,358,556	79,535,460	70,667,793
Foundation Insulation	1,622,345	2,683,570	5,948,598	9,839,755	50,292,689	83,190,660
Lighting	2,963,160	2,300,746	10,864,920	8,436,069	91,857,960	71,323,131
Duct Tightness	647,130	5,133,253	2,372,810	18,821,927	20,061,030	159,130,835
TOTAL	**$18,297,844**	**$13,928,770**	**$67,092,095**	**$51,072,157**	**$567,233,170**	**$431,791,873**

4.0 Conclusions

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

From a statewide perspective, the average home in Kentucky is now saving even more energy than a home exactly meeting the state energy code, moving from 7.9 percent less energy than a code home in Phase I to 13.2 percent less energy in Phase III as shown in Table 4.1. This results in over $300,000 in annual achieved savings, an improvement of nearly 24% following the Phase II targeted education and training activities as shown in Table 4.2. See Table 3.25 for potential total energy cost savings in each phase.

Table 4.1. Average Modeled Energy Use Intensity in Kentucky (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)
33.98	31.31	- 7.9%	29.49	-13.2%	-5.8%

The contributing factor to the reduction in measure-level savings potential was improvements in most key items: envelope air tightness, ceiling insulation, exterior wall insulation, and lighting, with envelope air tightness having a particularly positive change. Although foundation insulation and duct tightness still have opportunities for improvement, the savings potential overall decreased. While successful, the project does leave open unanswered questions such as the possible reasons for the increase in energy savings potential for duct tightness. More research would be required to determine the actual root causes of this increase. Possible causes include poor workmanship, inconsistent use of testing protocols, or inconsistent training of testers.

Table 4.2. Estimated Annual Statewide Cost Savings Potential

Measure	% Change Phase III vs. I
Envelope Air Tightness	97.9%
Ceiling Insulation	57.4%
Exterior Wall Insulation	11.1%
Foundation Insulation	-65.4%

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

Lighting	22.4%
Duct Tightness	-793%
TOTAL	**23.9%**

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 to identify ongoing opportunities to hone education and training programs.

5.0 References

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Appendix A

Stakeholder Participation

Appendix A

Stakeholder Participation

A.1 Stakeholder Participation

Table A.1. Stakeholder Participation in Project Kickoff Meeting

Stakeholder	Description
DHBC	State code agency responsible for adoption (and some enforcement) of the energy code.
DEDI	State energy agency.
HBAK and HBANK	Trade organizations representing builders, remodelers, developers and affiliated professionals.
Utilities	Includes gas utilities, generation and transmission electric utilities, and distribution cooperatives.
Appraisers	Establish worth of homes and by extension the worth of the measures used to meet code.
Mountain Association for Community Economic Development (MACED)	Works with low income communities in Eastern Kentucky.
KY Housing Corp	Provides affordable housing.
KY Assoc. of Master Contractors	Trade association representing HVAC contractors.

Appendix B

State Sampling Plan

Appendix B

State Sampling Plan

B.1 State Sampling Plan

Table B.1. Phase I State Sampling Plan

Location	Sample	Actual
Adair	1	1
Anderson	1	1
Bell	1	1 (Knox)
Boone	4	4
Bowling Green, Warren	3	3
Boyd	1	1
Breckinridge	1	1
Bullitt	3	3
Christian	1	1
Daviess	2	2
Edmonson	1	1
Elizabethtown, Hardin	2	2
Fayette	5	5
Franklin	1	1 (Clark)
Grant	1	1 (Bourbon)
Graves	1	1 (Calloway)
Grayson	1	1
Henderson	1	1
Jefferson	5	5
Jessamine	4	4
Johnson	1	1 (Pike)
Laurel	2	2
Lawrence	1	1 (Rowan)
Lincoln	1	1
Logan	1	1
Madison	1	1
Mercer	1	1
Muhlenberg	1	1
Nelson	2	2
Oldham	3	3
Perry	1	1
Pulaski	1	1
Richmond, Madison	1	1
Shelby	1	1
Simpson	1	1 (Barren)
Spencer	1	1
Taylor	1	1
Warren	1	1
Woodford	1	1
Total	**63**	**63**

Table B.2. Phase III State Sampling Plan

Location	Sample	Actual
Anderson	1	1
Barren	1	1
Boone	4	4
Boyd	1	1 (Greenup)
Breckinridge	2	2 (Ohio)
Campbell	1	1
Clark	2	2 (Franklin)
Daviess	3	3
Fayette	5	5
Grant	1	1
Hardin	3	3
Henderson	1	1
Hopkins	1	1
Jefferson	8	8
Jessamine	3	3
Kenton	3	3
Laurel	1	1
Logan	1	1
Madison	2	2
McCracken	1	1
Meade	1	1
Marshall	1	1
Nelson	1	1
Oldham	2	2
Pike	1	1
Pulaski	1	1
Scott	4	4
Warren	4	4
Woodford	3	3
Total	**63**	**63**

B.2 Substitutions

In the Kentucky Phase I study there were seven substitutions of original sample counties and three substitutions in Phase III, all caused by lack of construction or building availability in areas targeted by the original statewide randomized sample. The substitute counties were selected to best match the demographics of the original county based on identifiers such as household income, per capita income, home value, poverty level, and proximity. These demographic criteria were supplemented with DHBC's input on local construction technique similarities and the overall appropriateness of the selected substitute county.

Appendix C

Additional Data

Appendix C

Additional Data

C.1 Additional Data Collected by Field Teams

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

The following is a sampling of the additional data items collected as part of the Kentucky 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)	2400	2900
Number of Stories	1.3	1.6
Number of Homes Visited	138	127

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

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

Table C.3. Number of Stories

No. of Stories	1	2	3	4+
Percentage (Phase I)	74%	28%	1%	0%
Percentage (Phase III)	52%*	48%**	0%	0%

*Includes homes of 1 and 1.5 stories
**Includes homes of 2 and 2.5 stories

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

C.1.1.2 Wall Profile

Table C.4. Wall Characteristics

Wall Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Framing Type			140	124
Frame Walls	100%	100%		
Mass Walls	0%	0%		
Framing Material			139	125
Wood	98%	100%		
Steel	2%	0%		
Framing Depth			138	115
4 inch	88%	89%		
6 inch	12%	11%		
Type of Wall Insulation			75	71
Cavity Only	89%	100%		
Cavity + Continuous	9%	0%		
Continuous Only	1%	0%		

C.1.1.3 Foundation Profile

Table C.5. Foundation Characteristics

Foundation Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Foundation Type			140	128
Basement	41%	47%		
Slab on Grade	35%	27%		
Crawlspace	24%	27%		
Basement Type			58	59
Conditioned	100%	97%		
Unconditioned	0%	3%		

C.1.1.4 Builder Profile

Table C.6. Builder Characteristics

Builder Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Number of Homes Built Annually	135	281	30	5*
Distribution of Number of Homes Built Annually			30	5*
Less than 10	20%	20%		
10 to 50	53%	0%		
50 to 99	0%	0%		
100+	27%	80%		

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

C.1.2 Compliance

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

C.1.2.1 Energy Code Used

Table C.7. Energy Code and Above Code Programs

Code or Above Code Program Used	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Energy Code Used			14	128
2009 IECC	100%	100%		
Was home participating in an above code program?			15	3
Yes	27%	100%		
No	73%	0%		
Which above code program?			4	3*
Energy Star for Homes	50%	0%		
HERS	50%	0%		
Not Observable	0%	100%		

*19 homes were listed as "not observable", but only 3 homes were listed as being part of an above code program.

C.1.3 Envelope

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

Table C.8. Thermal Envelope Characteristics

Thermal Envelope Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Was insulation labeled?			85	55
Yes	85%	95%		
No	15%	5%		
Did the attic hatch/door exhibit the correct insulation value?			55	48
Yes	40%	17%		
No	60%	83%		
Air Sealing in accordance with checklist[1]				
Thermal Envelope sealed?	85%	44%	78	66
Fenestration Sealed?	84%	100%	25	1
Openings around doors and windows sealed?	83%	97%	75	65
Utility penetrations sealed?	81%	67%	95	70
Dropped ceilings sealed?	90%	56%	20	25
Knee walls sealed?	75%	59%	24	32
Garage walls sealed?	82%	94%	57	64
Tubs and showers sealed?	70%	76%	66	45
Attic access openings sealed?	41%	47%	54	53
Rim joists sealed?	72%	64%	69	58
Other sources of infiltration sealed?	79%	55%	81	65
IC-rated light fixtures sealed?	100%	93%	65	76

C.1.4 Duct & Piping Systems

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

Table C.9. Duct & Piping System Characteristics

Duct & Piping System Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Duct location in conditioned space (average percentage)				
Supply	48%	55%	133	187
Return	51%	59%	133	196
Ducts entirely in conditioned space (number and percentage)				
Supply	53 duct systems (40%)	67 duct systems (36%)		
Return	55 duct systems (41%)	68 duct systems (35%)		

[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.

Duct & Piping System Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Ducts in unconditioned space insulation (R-value)				
Supply	7.3	7.2	25	25
Return	6.7	7.3	21	24
Ducts in attic insulation (R-value)				
Supply	7.7	7.2	58	70
Return	7.1	7.2	63	71
Pipe insulation (R-value)			105	106
Average	R-2.4	R-3		
Range	R-2 to R-3	All R-3		
Building cavities used as supply ducts	4%	7%	98	102
Air ducts sealed	81%	73%	91	92
Air handlers sealed	87%	96%	110	105
Filter boxes sealed	85%	86%	100	95

C.1.5 HVAC Equipment

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

C.1.5.1 Heating

Table C.10. Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			127	118
Gas	44%	43%		
Electricity	56%	57%		
System Type			117	130
Furnace	51%	51%		
Heat Pump	48%	48%		
Electric Resistance	1%	1%		
Average System Capacity			112	NA*
Furnace	59,600 Btu/hr	NA*		
Heat Pump	39,000 Btu/hr	NA*		
Electric Resistance	48,000 Btu/hr	NA*		
Average System Efficiency			81	NA*
Furnace	88 AFUE	NA*		
Heat Pump	8.2 HSPF	NA*		

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

C.1.5.2 Cooling

Table C.11. Cooling Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			94	87
Central AC	31%	41%		
Heat Pump	69%	57%		
Room AC	0%	1%		
Average System Capacity			89	82
Central AC	40,000 Btu/hr	34,000		
Heat Pump	38,000 Btu/hr	31,600		
Average System Efficiency	13.7 SEER	41.1 SEER	59	69

C.1.5.3 Water Heating

Table C.12. Water Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			94	98
Gas	31%	40%		
Electricity	68%	60%		
Wood	1%	0%		
System Type			83	93
Storage	84%	88%		
Tankless	16%	12%		
Average System Capacity	54 gal	53 gal	65	60
Average System Efficiency			24	57
Electric Storage (non-heat pump)	EF 0.91	EF 0.93	15	37
Electric Storage (heat pump)	EF 2.75[1]	EF 2.1	3	2
Electric Tankless	EF 0.9	No observations	1	0
Gas Storage	No observations	EF 0.71	0	15
Gas Tankless	EF 0.89	EF 0.94	6	3

[1] Three electric storage heat pump water heater efficiencies were originally noted in Phase I. Quality assurance activity at the end of Phase III indicated that two of these heat pump water heaters were really electric storage water heaters that were listed with an EF of 8. It is more likely that the EF should be 0.8, and without further information, these two water heaters were not included in the electric storage water average provided.

Table C.13. Water Heating System Storage Capacity Distribution

Capacity	< 50 gal	50-59 gal	60-69 gal	70-79 gal	80-89 gal	90+ gal
Phase I Percentage	2%	86%	3%	2%	6%	2%
Phase III Percentage	3%	87%	0%	5%	2%	3%

C.1.5.4 Ventilation

Table C.14. Ventilation Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			123	98
Exhaust Only	91%	94%		
AHU-Integrated	7%	6%		
Standalone ERV/HRV	2%	0%		
Exhaust Fan Type			111	93
Dedicated Exhaust	2%	0%		
Bathroom Fan	98%	100%		

C.1.5.5 Other

Table C.15. Other Mechanical System Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Mechanical Manuals Provided	84%	100%	77	30

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 Kentucky. Table D.3 and Table D.4 provide a breakdown of foundation insulation results by each foundation component in Phase I and Phase III, respectively. Also included are multi-year (5-year, 10-year, and 30-year) aggregations of the annual results in Table D.5 and Table D.6. The multi-year savings reflect the same reductions and increases as the annual savings and are simply the annual savings multiplied by 15, 55, and 465 for 5-year, 10-year, and 30-year savings, respectively. For analytical details refer to Section 2.3.3 (Savings Analysis) or the methodology report (DOE 2018).

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

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Tightness	442	22	3,701	7,345	27,182	484,314	3,092
Ceiling Insulation	213	8	1,548	7,345	11,372	215,656	1,080
Exterior Wall Insulation	163	7	1,263	7,345	9,277	171,044	1,102
Foundation Insulation*	195	15	2,153	7,003	6,800	108,156	668
Lighting**	300	-2	782	7,345	5,742	197,544	1,427
Duct Tightness	46	1	291	7,345	2,135	43,142	284
TOTAL	**1,359**	**51**	**9,738**	**Varies**	**62,508**	**1,219,856**	**7,653**

*See Table D.3 for annual measure-level savings results by foundation type.
** Negative values mean that savings or reductions decrease if the measure is brought up to code. For example, for lighting, increasing the amount of high-efficacy lighting reduces electrical usage, but increases natural gas usage for heating, as the heat from less efficient bulbs must be replaced.

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

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Tightness	9.37	0.47	79	7,345	581	10,321	65.5
Ceiling Insulation	90.81	3.49	659	7,345	4,835	91,786	595.0
Exterior Wall Insulation	145.03	6.28	1,123	7,345	8,243	151,974	976
Foundation Insulation*	429	39	5,395	Varies	11,676	178,905	1,075
Lighting**	233.26	-1.89	607	7,345	4,454	153,383	1,130
Duct Tightness	358.30	11.14	2,336	7,345	17,151	342,217	2,251
TOTAL	**1265.88**	**58.79**	**10,198**	**Varies**	**46,941**	**928,585**	**6,093**

*See Table D.4 for annual measure-level savings results by foundation type.
** 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 Statewide Annual Measure-Level Savings by Foundation Type for Kentucky*

Measure	Electricity Savings (kWh/home)	Natural Gas Savings (therms/home)	Total Savings (kBtu/home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Basement Wall Insulation	132	10	1,491	3,929	5,859	92,987	574
Slab Insulation	62	3	553	1,367	756	13,084	83
Floor Insulation	2	1	108	1,708	185	2,086	11
TOTAL	**195**	**15**	**2,153**	**7,003**	**6,800**	**108,156**	**668**

* For foundation measures, the total number of homes is multiplied by the foundation share for each foundation type and is therefore smaller than the total number of homes shown for other measures.

Table D.4. Phase III Statewide Annual Measure-Level Savings by Foundation Type for Kentucky*

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Basement Wall Insulation	172	13	1,933	3,929	7,594	120,851	737
Slab Insulation	106	6	947	1,367	1,294	22,447	141
Floor Insulation	41	13	1,412	1,708	2,412	29,362	158
Crawlspace Wall Insulation	110	7	1,103	342	377	6,245	39
TOTAL	**429**	**39**	**5,395**	**Varies**	**11,676**	**178,905**	**1,075**

* For foundation measures, the total number of homes is multiplied by the foundation share for each foundation type and is therefore smaller than the total number of homes shown for other measures.

Table D.5. Phase I Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings for Kentucky

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Envelope Air Tightness	407,730	1,495,010	12,639,630	7,264,710	26,637,270	225,206,010	46,380	170,060	1,437,780
Ceiling Insulation	170,580	625,459	5,287,971	3,234,844	11,861,095	100,280,170	16,197	59,387	502,092
Exterior Wall Insulation	139,155	510,235	4,313,805	2,565,660	9,407,420	79,535,460	16,530	60,610	512,430
Foundation Insulation	101,997	373,989	3,161,903	1,622,345	5,948,598	50,292,689	10,019	36,735	310,579
Lighting	86,130	315,810	2,670,030	2,963,160	10,864,920	91,857,960	21,405	78,485	663,555
Duct Tightness	32,025	117,425	992,775	647,130	2,372,810	20,061,030	4,260	15,620	132,060
TOTAL	**937,620**	**3,437,939**	**29,066,211**	**18,297,844**	**67,092,095**	**567,233,170**	**114,792**	**420,902**	**3,558,537**

Table D.6. Phase III Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings for Kentucky

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
	5yr	10yr	30yr	5yr	10yr	30yr	5yr	10yr	30yr
Envelope Air Tightness	8,720	31,972	270,309	$154,808	$567,628	$4,799,034	982	3,602	30,454
Ceiling Insulation	72,532	265,951	2,248,499	$1,376,788	$5,048,222	$42,680,420	8,925	32,723	276,661
Exterior Wall Insulation	123,649	453,378	3,833,104	$2,279,606	$8,358,556	$70,667,793	14,644	53,694	453,957
Foundation Insulation	175,136	642,164	5,429,207	$2,683,570	$9,839,755	$83,190,660	16,132	59,152	500,101
Lighting	66,810	244,969	2,071,100	$2,300,746	$8,436,069	$71,323,131	16,949	62,146	525,416
Duct Tightness	257,272	943,330	7,975,427	$5,133,253	$18,821,927	$159,130,835	33,767	123,812	1,046,771
TOTAL	**704,118**	**2,581,765**	**21,827,645**	**$13,928,770**	**$51,072,157**	**$431,791,873**	**91,399**	**335,129**	**2,833,360**

Table D.7 Comparison of Five-year, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Phase III vs. Phase I

Measure	Potential Total Energy Cost Savings ($) 5 yr		Potential Total Energy Cost Savings ($) 10 yr		Potential Total Energy Cost Savings ($) 30 yr	
	Phase I	Phase III	Phase I	Phase III	Phase I	Phase III
Envelope Air Tightness	7,264,710	154,808	26,637,270	567,628	225,206,010	4,799,034
Ceiling Insulation	3,234,844	1,376,788	11,861,095	5,048,222	100,280,170	42,680,420
Exterior Wall Insulation	2,565,660	2,279,606	9,407,420	8,358,556	79,535,460	70,667,793
Foundation Insulation	1,622,345	2,683,570	5,948,598	9,839,755	50,292,689	83,190,660
Lighting	2,963,160	2,300,746	10,864,920	8,436,069	91,857,960	71,323,131
Duct Tightness	647,130	5,133,253	2,372,810	18,821,927	20,061,030	159,130,835
TOTAL	**$18,297,844**	**$13,928,770**	**$67,092,095**	**$51,072,157**	**$567,233,170**	**$431,791,873**

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