PNNL-26727

Kentucky Residential Energy Code Field Study: Baseline Report

August 2017

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

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
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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 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 data has led to a better understanding of the energy features present in homes, and indicates over $1,200,000 in potential annual savings to Kentucky homeowners that could result from increased code compliance. Public and private entities within the state can use this information to justify and catalyze future investments in energy code training and related energy efficiency programs.

Methodology

The project team was led by the 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. The team applied a methodology prescribed by the U.S. Department of Energy (DOE), which was based on collecting information for the energy code-required building components with the largest direct impact on energy consumption. These *key items* are a focal point of the study, and in turn drive the analysis and savings estimates. The project team implemented a customized sampling plan representative of new construction within the state, which was originally developed by Pacific Northwest National Laboratory (PNNL), and then vetted through public meetings with key stakeholders in the state.

Following data collection, PNNL conducted three stages of analysis on the resulting data set (Figure ES.1). The first stage identified compliance trends within the state based on 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 the potential energy savings, consumer cost savings, and avoided carbon emissions associated with increased code compliance. Together, these findings provide valuable insight on challenges facing energy code implementation and enforcement.

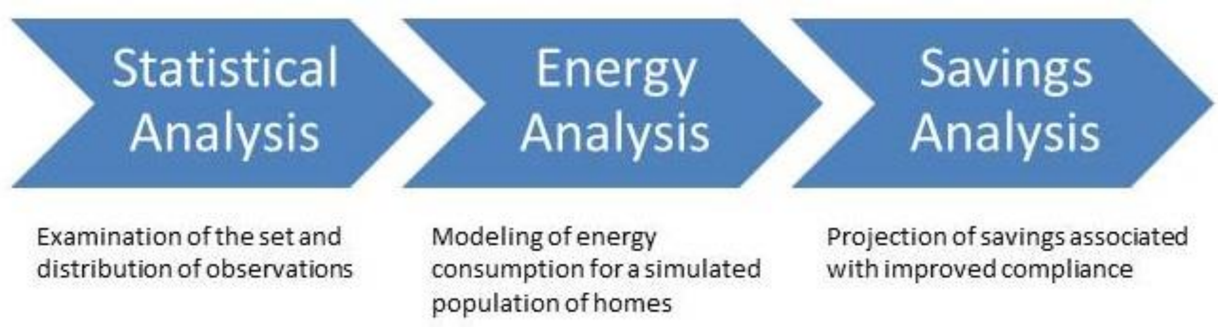

Figure ES.1. Stages of Analysis Applied in the Study

Results

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

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

Measure	**Total Energy Savings** (MMBtu)	**Total Energy Cost Savings** ($)	**Total State Emissions Reduction** (MT CO2e)
Envelope Air Leakage	27,182	484,314	3,092
Ceiling Insulation	11,372	215,656	1,080
Exterior Wall Insulation	9,277	171,044	1,102
Foundation Insulation	6,800	108,156	668
Lighting	5,742	197,544	1,427
Duct Leakage	2,135	43,142	284
TOTAL	**62,508 MMBtu**	**$1,219,856**	**7,653 MT CO2e**

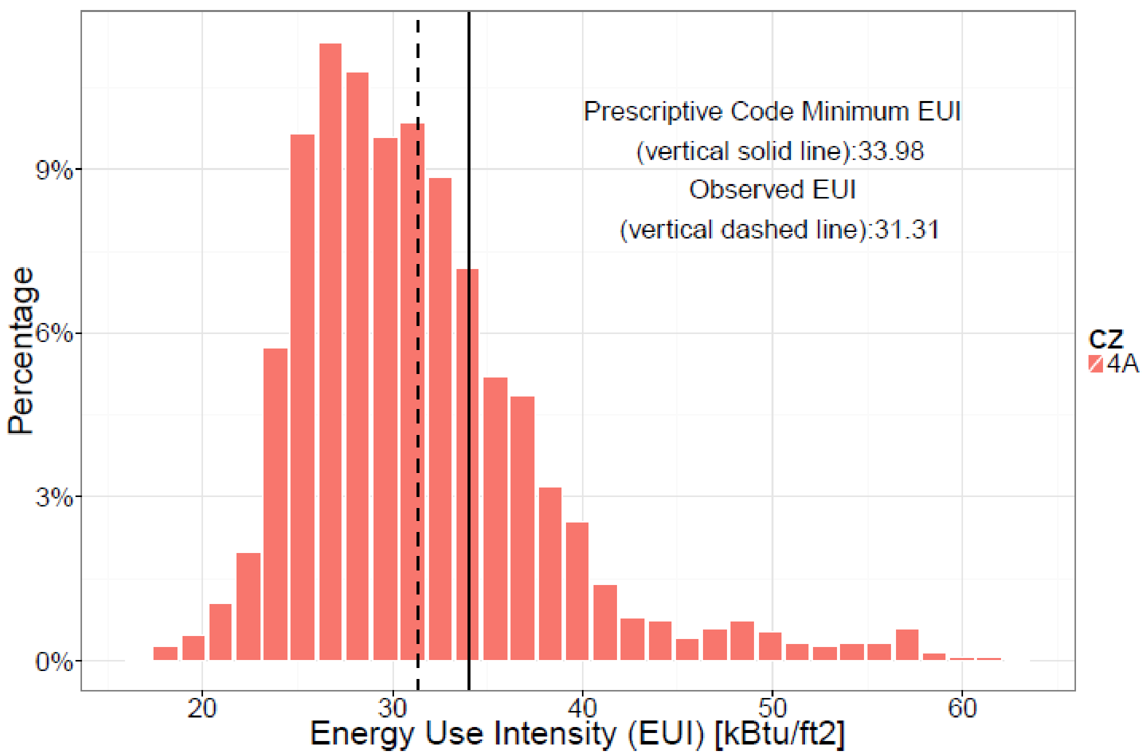

Figure ES.2. Modeled Distribution of Regulated EUI (kBtu/ft^2/year) in Kentucky

In terms of overall energy consumption, the analysis shows that homes within the state use *less* energy than would be expected relative to homes built to the current minimum state code requirements (Figure ES.2). Analysis of the collected field data indicates an average regulated energy use intensity (EUI) of 31.31 kBtu/ft^2-yr statewide compared to 33.98 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements. This suggests that on average the typical home in the state is about 7.8% better than code.

Acknowledgments

The following members comprised the Kentucky project team:

- Isaac Elnecave, *Midwest Energy Efficiency Alliance (MEEA)*
- Chris Burgess, *MEEA*
- Kelsey Horton, *MEEA*
- Roger Banks, *Kentucky Department of Housing, Buildings and Construction (DHBC)*
- 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, *Cadmus*
- Nigel Makela, *Cadmus*
- Jolyn Green, *Cadmus*

MEEA

The Midwest Energy Efficiency Alliance (MEEA) 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/Pages/default.aspx.

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
ACCA	Air Conditioning Contractors of America
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
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
kBtu	thousand British thermal units
KY	Kentucky
MMBtu	million British thermal units
MT	metric ton
NA	not applicable
PNNL	Pacific Northwest National Laboratory
RFI	request for information
SHGC	solar heat gain coefficient

Contents

Figures

Tables

1.0 Introduction

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

The Kentucky field study 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. At the time of the study, the state had the 2009 International Energy Conservation Code (IECC). The study methodology, data analysis and resulting findings are presented throughout this report.

1.1 Background

The data collected and analyzed for this report was in response to the U.S. Department of Energy (DOE) Funding Opportunity Announcement (FOA), "Strategies to Increase Residential Energy Code Compliance Rates and Measure Results".[1] The goal of the FOA is to determine whether an investment in education, training, and outreach programs can produce a significant, measurable change in single-family residential building code energy use, and therefore energy savings, within 2-3 years. Participating states are:

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

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

1.2 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

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

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

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

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

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

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

Members of these and other groups are critical to the success of the project, as they hold important information (e.g., building officials have the lists of homes under construction and are therefore key to the sampling process), control access to homes needed for site visits, are targets for training, or, as is often the case with government agencies, have oversight responsibilities for code adoption and implementation. Utilities were also identified as a crucial stakeholder. Many utilities have expressed an increasing interest in energy code investments, and are looking at energy code compliance as a means to provide assistance. The field study is aimed specifically at providing a strong, empirically-based case for such utility investment.

2.0 Methodology

2.1 Overview

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

Highlights of the methodology:

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

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

1. Envelope tightness (ACH at 50 Pascals)
2. Windows (U-factor & SHGC)
3. Wall insulation (assembly U-factor)
4. Ceiling insulation (R-value)
5. Lighting (% high-efficacy)
6. Foundation insulation (R-value 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.

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

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

collection and analysis methodology is published separately from this report (DOE 2016) and is available on the DOE Building Energy Codes Program website.[3]

2.2 State Study

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

2.2.1 Sampling

PNNL developed a statewide sampling plan statistically representative of recent construction activity within the state. 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. The sampling plan specified the number of key item observations required in each selected county (totaling 63 of each key item across the entire state). Kentucky comprises a single climate zone (CZ4), therefore there is no differentiation of results by climate.

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

2.2.2 Data Collection

Following confirmation of the sample plan, the Department of Housing, Buildings and Construction (DHBC) provided lists of homes permitted within the last 12 months for each of the sampled counties. These lists were then sorted using a random number generator and utilized by the team's in-state program manager (a retired code official with DHBC) to contact builders to gain permission for site access. That information was then passed onto the data collection team who arranged a specific time for a site visit. As prescribed by the methodology, each home was visited only once to avoid any bias associated with multiple site visits. Only installed items directly observed by the field teams during site visits were recorded. If access was denied for a particular home on the list, field personnel moved onto the next home on the list.

2.2.2.1 Data Collection Form

The field teams relied on a data collection form customized to the mandatory and prescriptive requirements of the state energy code (the 2009 IECC with Kentucky-specific amendments[5]). The final data collection form is available in spreadsheet format on the DOE Building Energy Codes Program

[3] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study.
[4] Available at http://censtats.census.gov/ (select the "Building Permits" data).
[5] The Kentucky code is available at http://dhbc.ky.gov/Documents/2013%20KRC%202nd%20Edition%20%28February%202014%29%20-%204.8.2014.pdf.

website.[6] The form included all energy code requirements (i.e., not just the eight key items), as well as additional items required under the prescribed methodology. For example, the field teams were required to conduct a blower door test and duct leakage test on every home where such tests could be conducted, using RESNET[7] protocols.

The information beyond the key items was used during various phases of the analysis, or to supplement the overall study findings. For example, insulation installation quality impacts the energy-efficiency of insulation and was therefore used to modify that key item during the energy modeling and savings calculation. Equipment such as fuel type and efficiency rating, and basic home characteristics (e.g., foundation type) helped validate the prototype models applied during energy simulation. Other questions, such as whether the home participated in an above-code program, can assist in understanding whether other influencing factors are at play beyond the code requirements.

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 DOE's older work, simply stated whether an item did or did not comply. 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 energy code.

2.2.2.2 Data Management and Availability

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

2.3 Data Analysis

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

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

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

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

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.

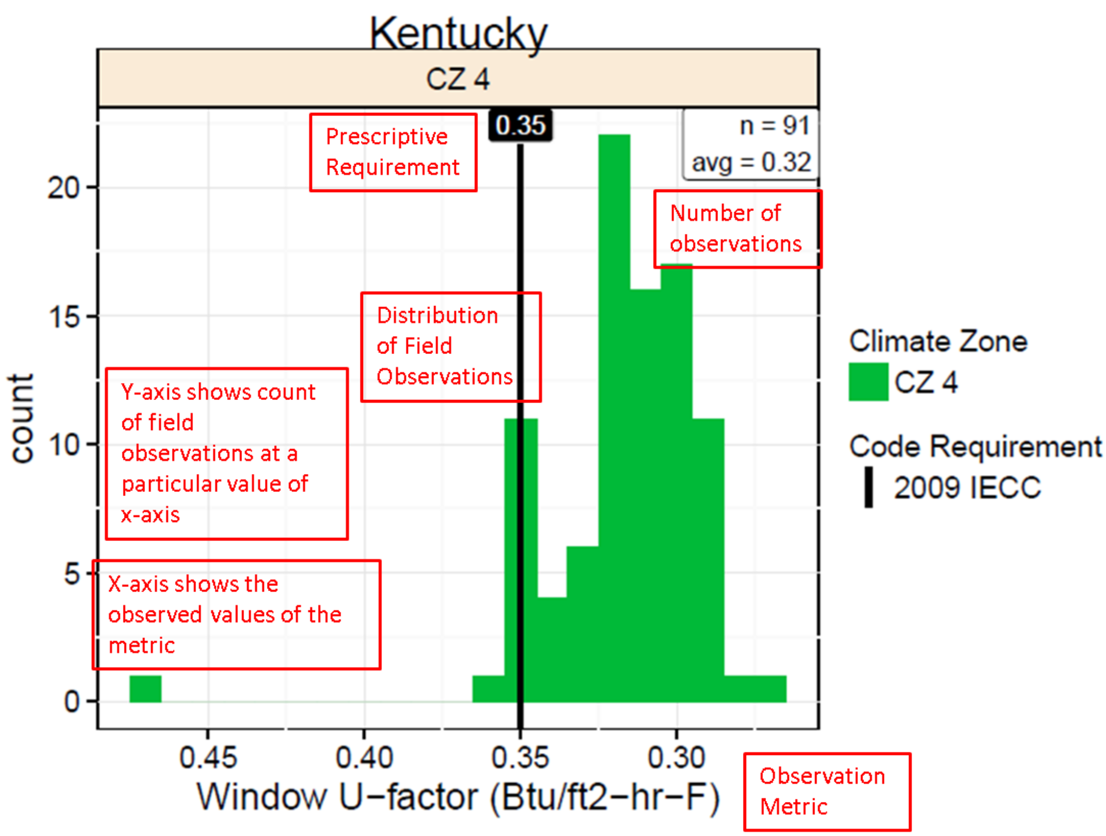

Figure 2.1. Sample Graph

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 are *better than code*. Values to the left-hand side represent areas for improvement.

2.3.2 Energy Analysis

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

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

Further specifics of the energy analysis are available in a supplemental methodology report (DOE 2016).[10]

2.3.3 Savings Analysis

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

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

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

[11] "Significant" was defined as 15% or more of the observed values not meeting the associated code requirement. Only the items above this threshold were analyzed.

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

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 CO_2e).

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.

2.4 Limitations

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

2.4.1 Applicability of Results

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

2.4.2 Determination of Compliance

The field study protocol is based upon a single site visit, which makes it impossible to know whether a particular home complies with the energy code as not enough information can be gathered in a single visit to know whether all code requirements have been met. For example, homes observed during the earlier stages of construction often lack key features (e.g., walls with insulation), and in the later stages many of these items may be covered and therefore unobservable. To gather all the data required in the sampling plan, field teams therefore needed to visit homes in various stages of construction. The analytical implications of this are described above in Section 2.3.2. This approach gives a robust representation of measure compliance across the state.

2.4.3 Sampling Substitutions

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

2.4.4 Site Access

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

2.4.5 Analysis Methods

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

2.4.6 Presence of Tradeoffs

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

3.0 State Results

3.1 Field Observations

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

3.1.1 Key Items

The field study and underlying methodology are driven by *key items* that have a significant direct impact on residential energy efficiency. The graphs presented in this section represent the key item results for the state based on the measures observed in the field. Note that these key items are also the basis of the results presented in the subsequent *energy* and *savings* phases of analysis.

The following key items were found applicable within the state:

1. Envelope tightness (ACH at 50 Pascals)
2. 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 three crawlspace wall observations, but due to that small number, graphics are only provided for conditioned basements, floors, and slabs.

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

3.1.1.1 Envelope Tightness

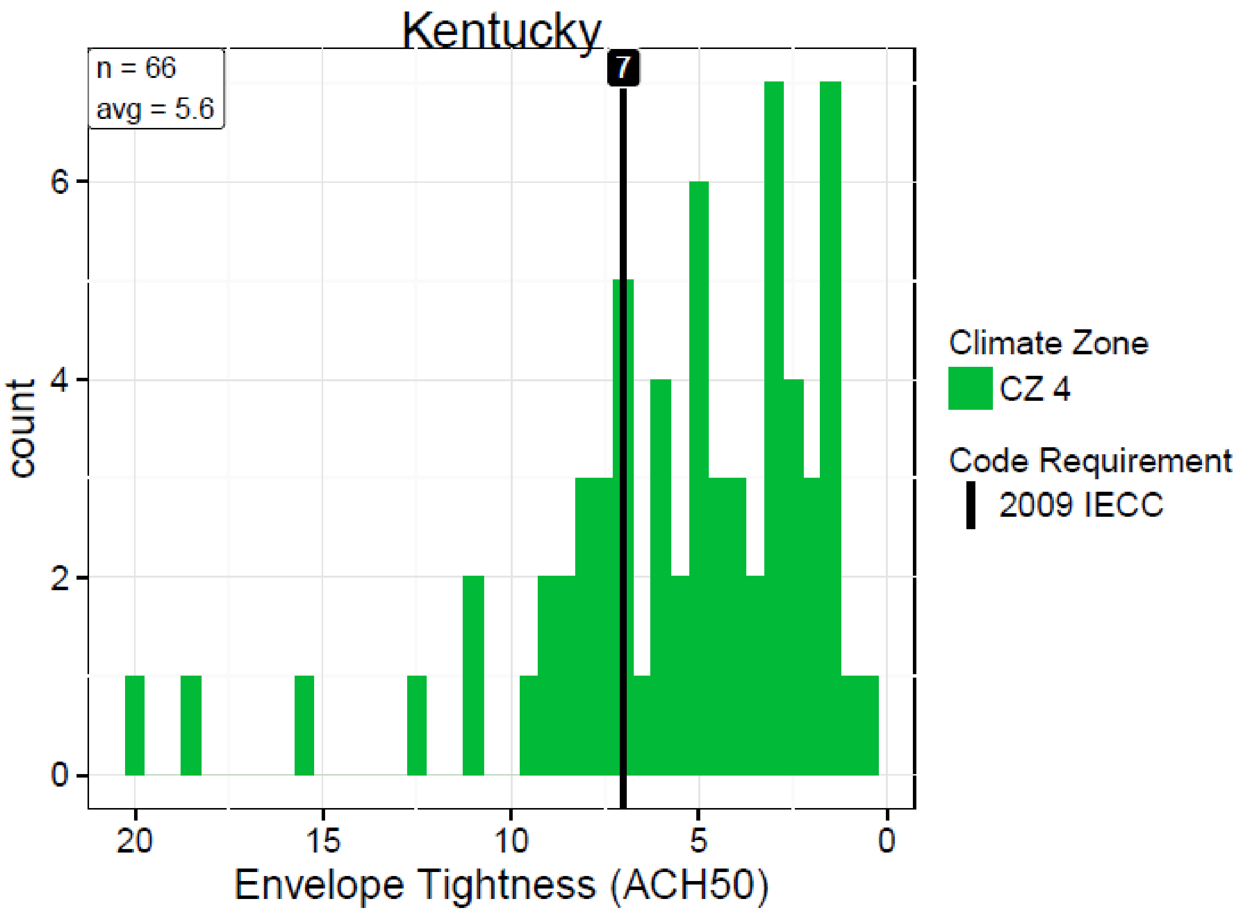

Figure 3.1. Envelope Tightness (ACH50)

- **Requirement:** 7.0 ACH50 (CZ4)
- **Observations:**
  - Number: 66
  - Range: 20.00 to 0.51 ACH50
  - Average: 5.6 ACH50
  - Compliance Rate: 46 of 66 (70%)
- **Interpretations:**
  - Over half of the observations met or exceeded the prescriptive code requirement, and the remaining observations were in the 7 to 20 ACH50 range.
  - Reductions in envelope air leakage represent an area for improvement in the state, and should be given attention in future training and enforcement.

Doors, windows and others parts of the thermal envelope were generally sealed (typically around 80% on most specific checklist items). However, these results are from checklist items that are addressed via visual inspection. When comparing these visual results with the actual blower door testing results (envelope tightness), it is clear that there can be significant differences in the two ways of evaluating envelope sealing.

3.1.1.2 Window SHGC

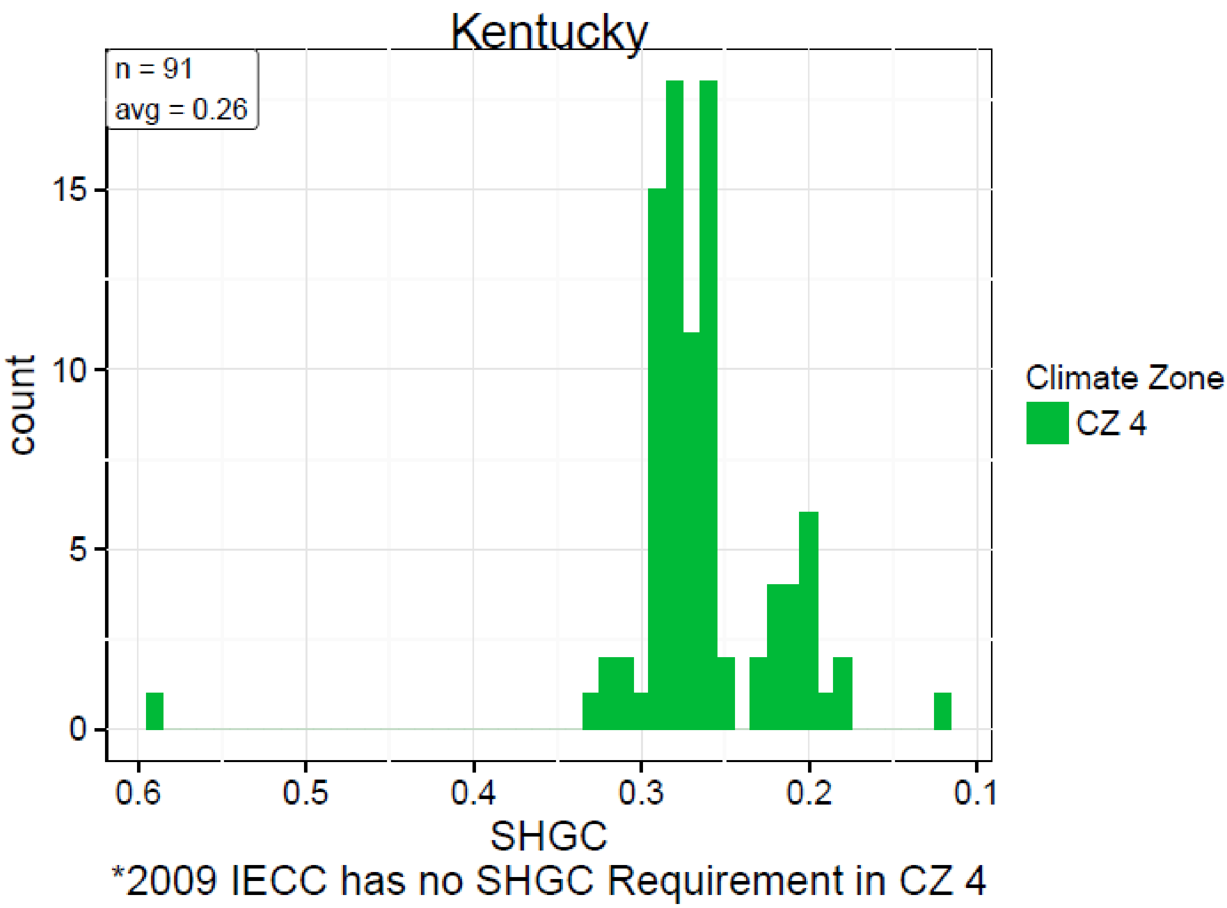

Figure 3.2. Window SHGC

- **Requirement**: NA in Kentucky (CZ4)
- **Observations:**
  - Number: 91
  - Range: 0.59 to 0.12
  - Average: 0.26
  - Compliance Rate: NA
- **Interpretations:**
  - SHGC values were fairly consistent, and nearly meet the prescriptive requirement for Climate Zones 1-3.
  - The vast majority of the observations were in the 0.20 to 0.30 SHGC range.

3.1.1.3 Window U-Factor

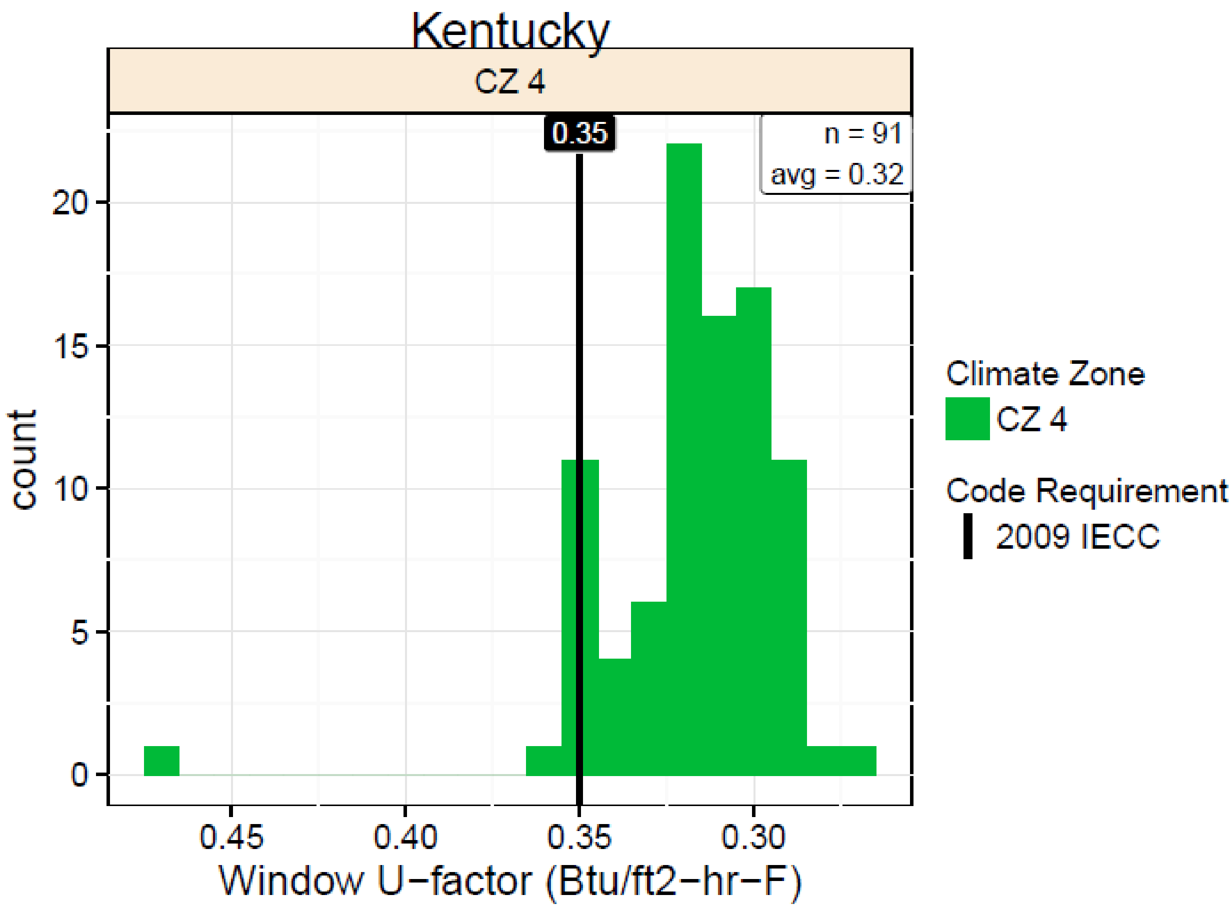

Figure 3.3. Window U-Factor

- **Requirement**: U-0.35 (CZ4)
- **Observations:**
  - Number: 91
  - Range: 0.49 to 0.27
  - Average: 0.32
  - Compliance Rate: 89 of 91 (98%)
- **Interpretations:**
  - There is an extremely high rate of compliance for fenestration products in the state.
  - This represents one of the most significant findings of the field study, with nearly all of the observations at or above the code requirement.
  - Window U-factor requirements appear to have been implemented with a high rate of success across the state.

3.1.1.4 Wall Insulation

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

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

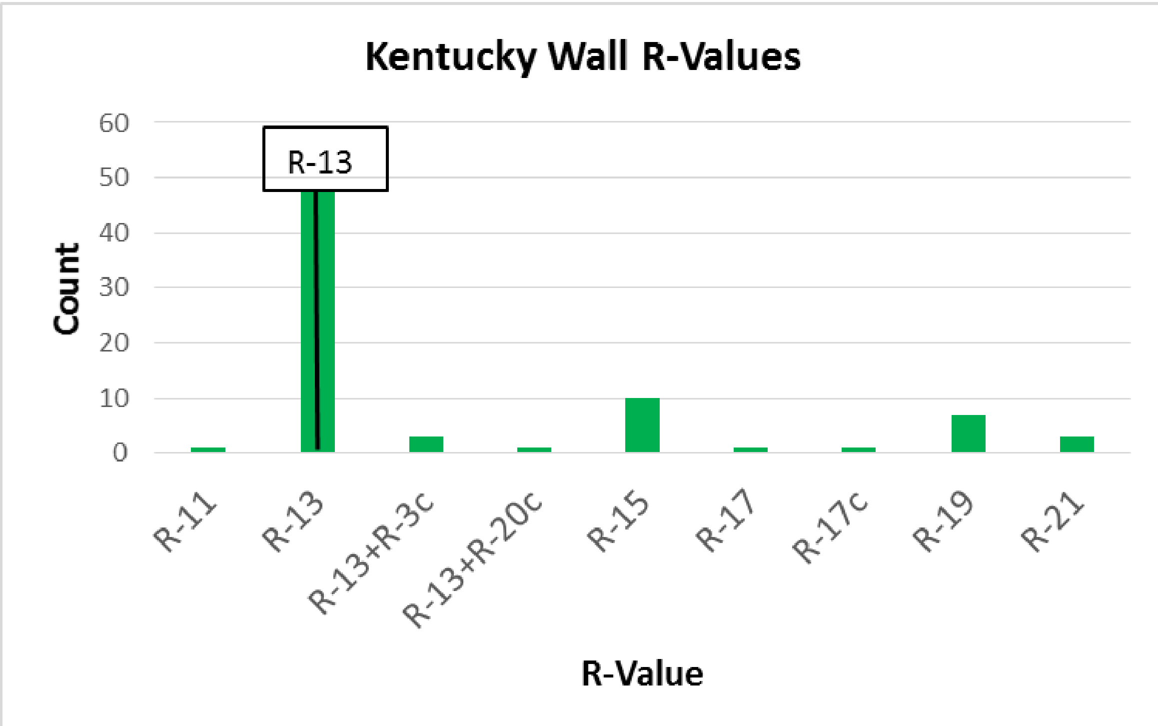

Figure 3.4. Kentucky Wall R-Values

Figure 3.5 represents overall wall assembly performance (U-factor). The U-factor perspective takes into account combined insulation values (any cavity and/or continuous insulation that was installed in the home), as well as framing, and insulation installation quality, as observed in the field. This approach illustrates the additional savings possible through proper installation. In the graph, observations are binned for clearer presentation based on the most commonly observed combinations.

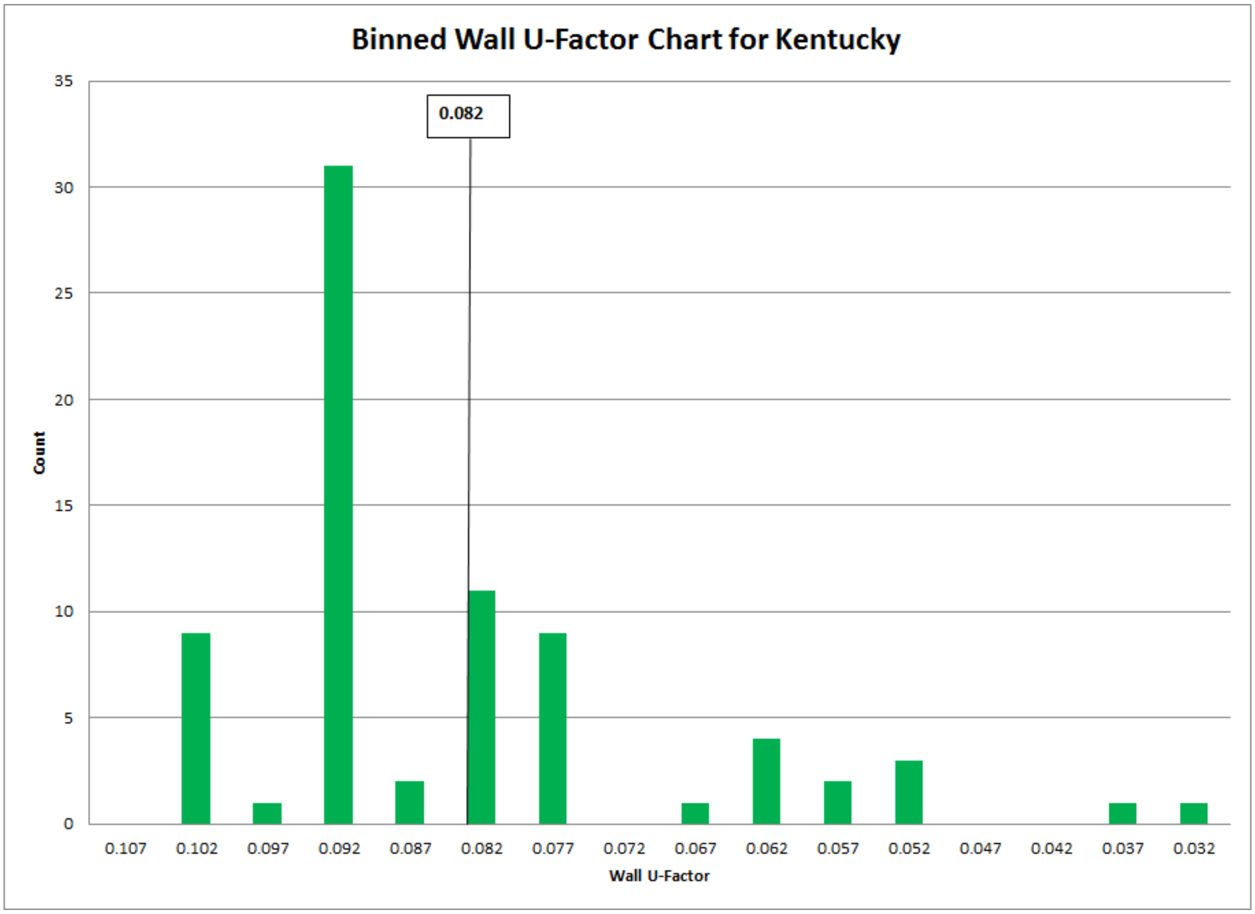

Figure 3.5. Kentucky Wall Assembly Performance, including Insulation Installation Quality

- **Assembly U-Factor (expected):** 0.082 (CZ4)
- **Observations:**
  - Number: 75
  - Range: 0.102 to 0.029
  - Average: 0.084
  - Assembly U-Factor (expected): 21 of 75 (28%)
- **Interpretations:**
  - 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.).
  - Cavity insulation is achieved at a high rate—nearly all the observations met or exceeded the prescriptive code requirement for wall cavity insulation (based on labeled R-value).
  - From an assembly perspective, a majority of observations had Grade II and Grade III insulation installation quality. A more detailed discussion of insulation installation quality is included at the end of the section (3.1.2).

– While cavity insulation appears to be achieved successfully (R-value), the overall assembly performance (U-factor) exhibits room for improvement—this can be a focal point for future education and training activities in the state.

3.1.1.5 Ceiling R-Value

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

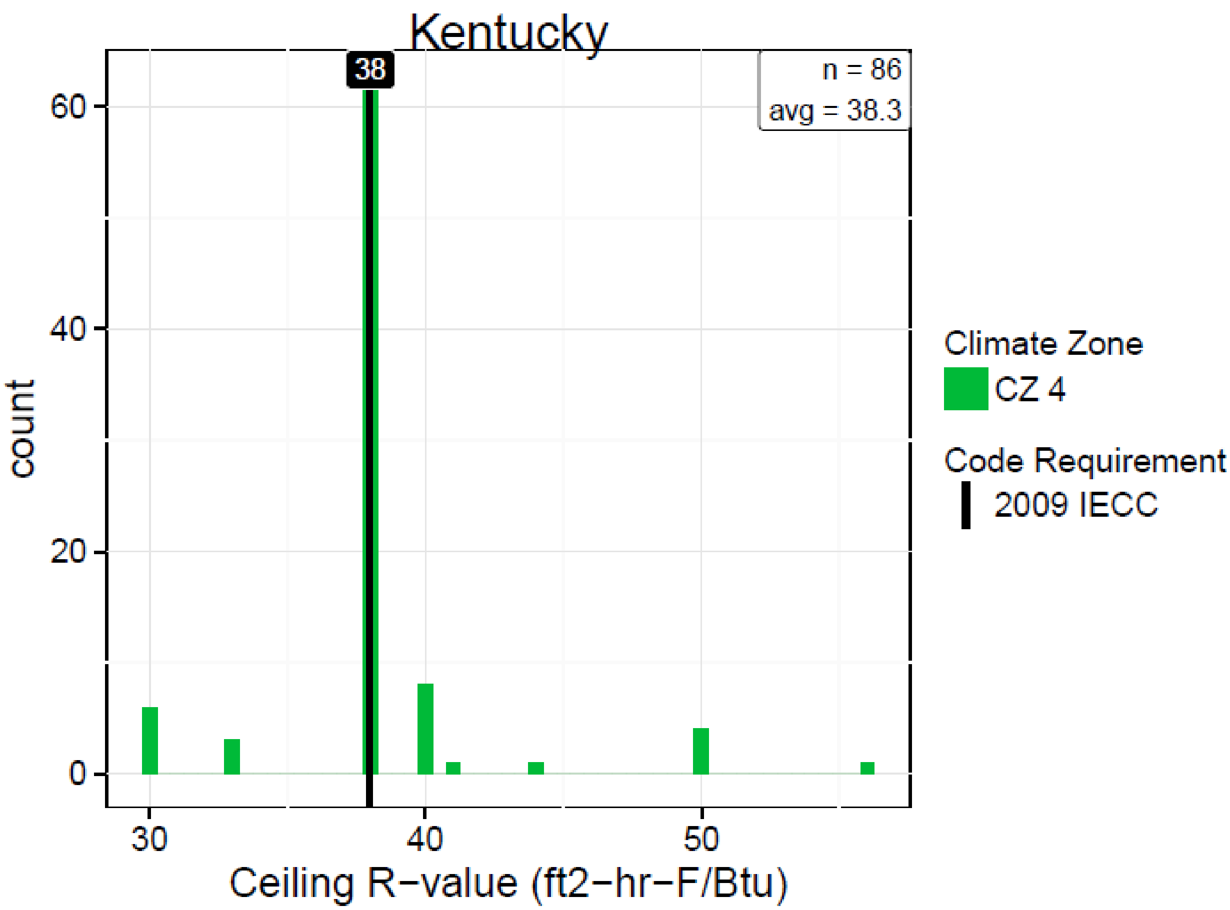

Figure 3.6. Ceiling R-Value

- **Requirement**: R-38 (CZ4)
- **Observations:**
  - Number: 86
  - Range: R-30 to R-56
  - Average: R-38
  - Compliance Rate: 77 of 86 (90%)

Figure 3.7 represents the calculated U-factors, including the effects of insulation installation quality, for Kentucky observations.

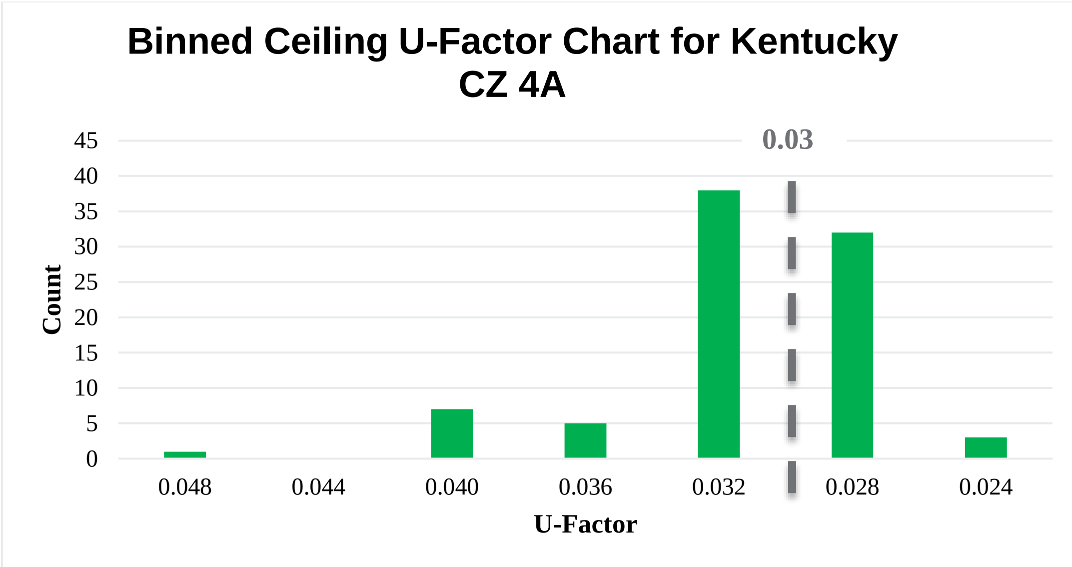

Figure 3.7. Ceiling U-Factor

- **Assembly U-Factor (expected)**: 0.03 (CZ4)
- **Observations:**
  - Number: 86
  - Range: 0.024 to 0.047
  - Average: 0.033
  - Assembly U-factor (expected): 35 of 86 (41%)
- **Interpretations:**
  - The majority of R-value observations meet the code requirement exactly.
  - 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.
  - Overall, the amount of ceiling insulation does not appear to be an issue in the state.
  - From an assembly perspective, a majority of observations had Grades II or III in terms of insulation installation quality. This should be a focal point for future education and training activities in the state.

3.1.1.6 Lighting

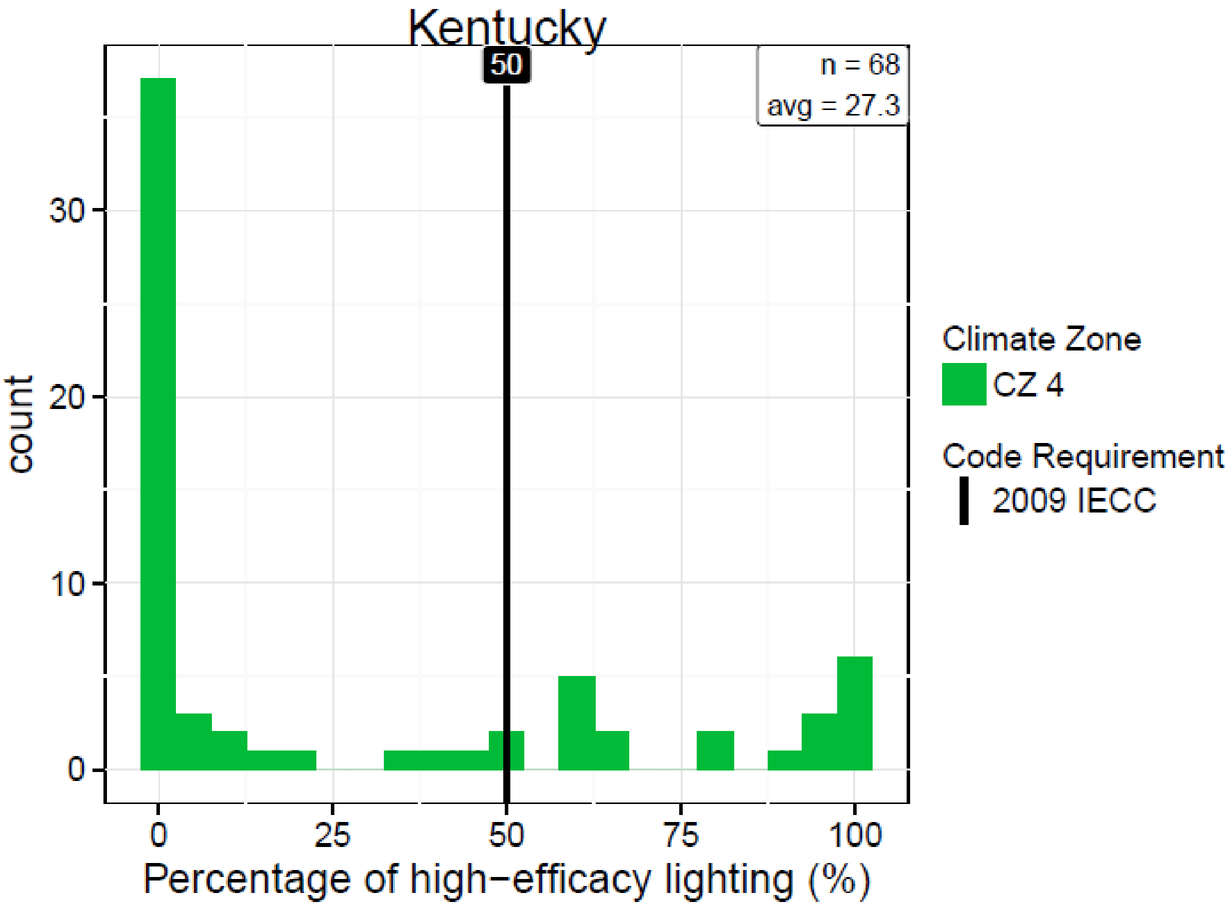

Figure 3.8. High-efficacy Lighting Percentage

- **Requirement**: 50% high-efficacy
- **Observations:**
  - Number: 68
  - Range: 0 to 100
  - Average: 27
  - Compliance Rate: 21 of 68 (31%)
- **Interpretations:**
  - Less than one-third of the field observations were observed to meet the requirement; a much lower number than expected.
  - The most common observations were at 0%.
  - This represents an area of significant savings potential and should be considered an area for increased attention in future training and enforcement within the state.

3.1.1.7 Foundation Assemblies

There were three predominant foundation types observed in Kentucky: conditioned basements, floors, and slabs.[2] 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 insulation installation quality, 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 basement wall R-values, the plots show two sets of data; orange bars indicate basement walls insulated only with continuous insulation, while purple bars indicate basement walls insulated with cavity insulation only or a combination of cavity and continuous insulation. This approach was taken to differentiate between cavity and continuous insulation requirements. For slabs, only an R-value graph is shown.

While initially combined into a single key item (i.e., foundation assemblies[3]), the variety of observed foundation types are 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 is anticipated to be of value for energy code training programs. From a savings perspective, results are calculated for both the aggregated perspective individual foundation types (presented later in Section 3.3), however; only the aggregated observations should be considered statistically representative at the statewide level.

[2] While there were many homes listed as having crawlspaces, only 3 observations of crawlspace wall insulation were made. For this reason, crawlspace wall insulation is not included as key item or as a measure level savings item in Section 3.3.

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

Basement Walls

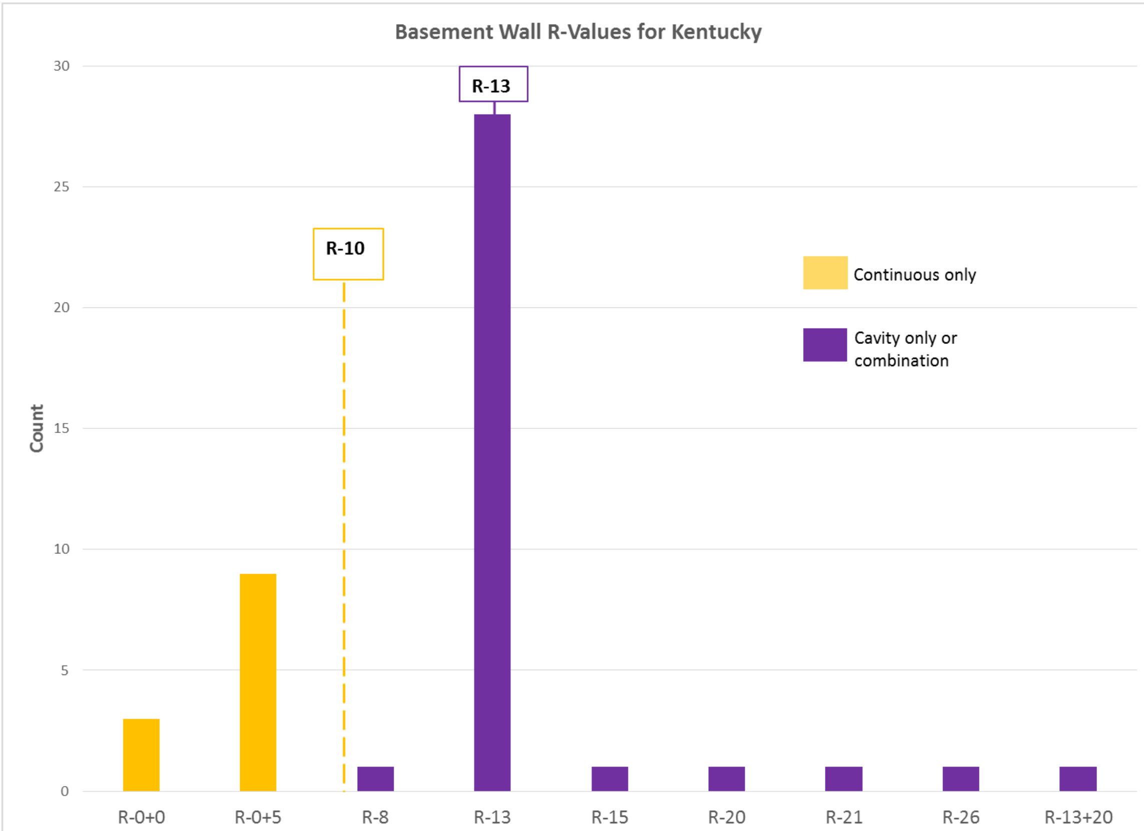

Figure 3.9. Basement Wall R-Values for Kentucky

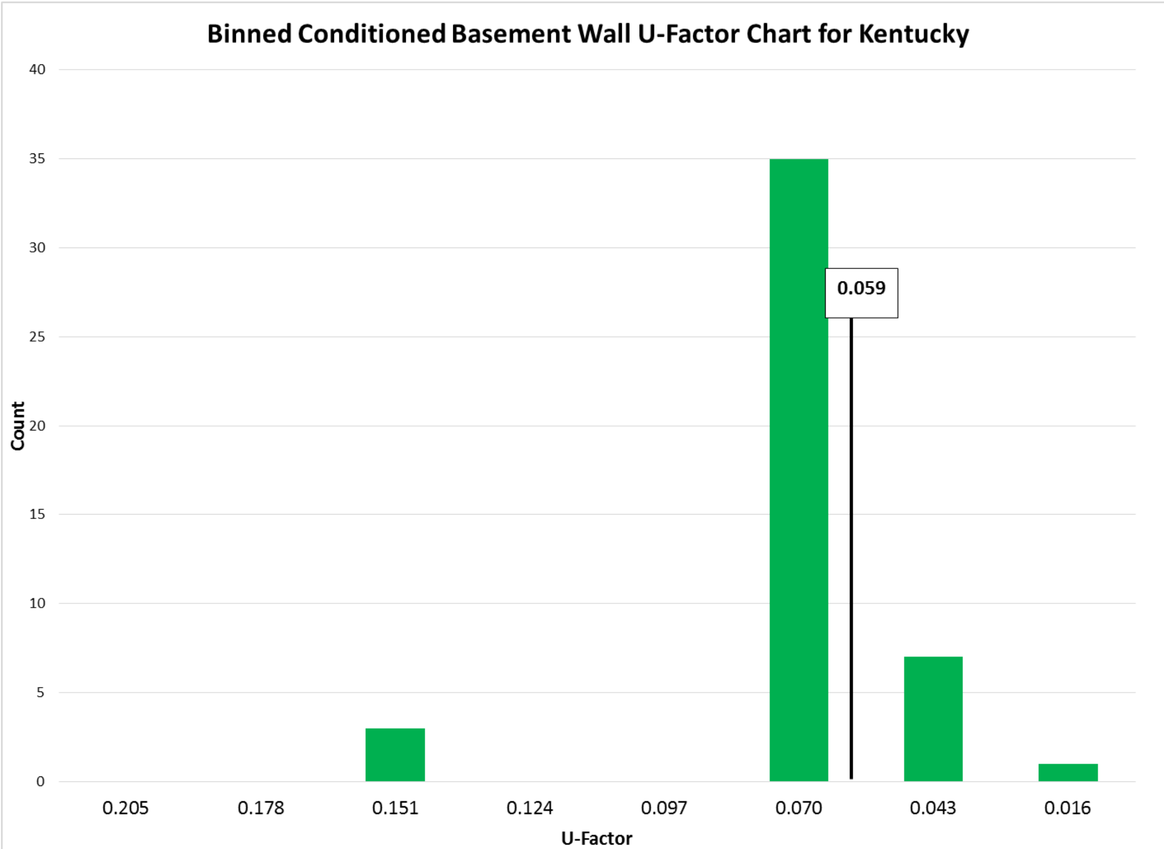

Figure 3.10. Binned Conditioned Basement Wall U-Factor for Kentucky

- **Assembly U-Factor (expected):** 0.059
- **Observations:**
  - Number: 46
  - Range: U-0.163 to U-0.026
  - Average: U-0.068
  - Rate: 8 of 46 (18%)
- **Interpretations:**
  - The R-value graph indicates that no basement walls with continuous insulation met the requirement (12 observations), 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. The majority of these observations (23) have R-13 cavity insulation with Grade II or Grade III insulation installation quality, indicating that insulation installation quality is an issue for basement walls.

Floors

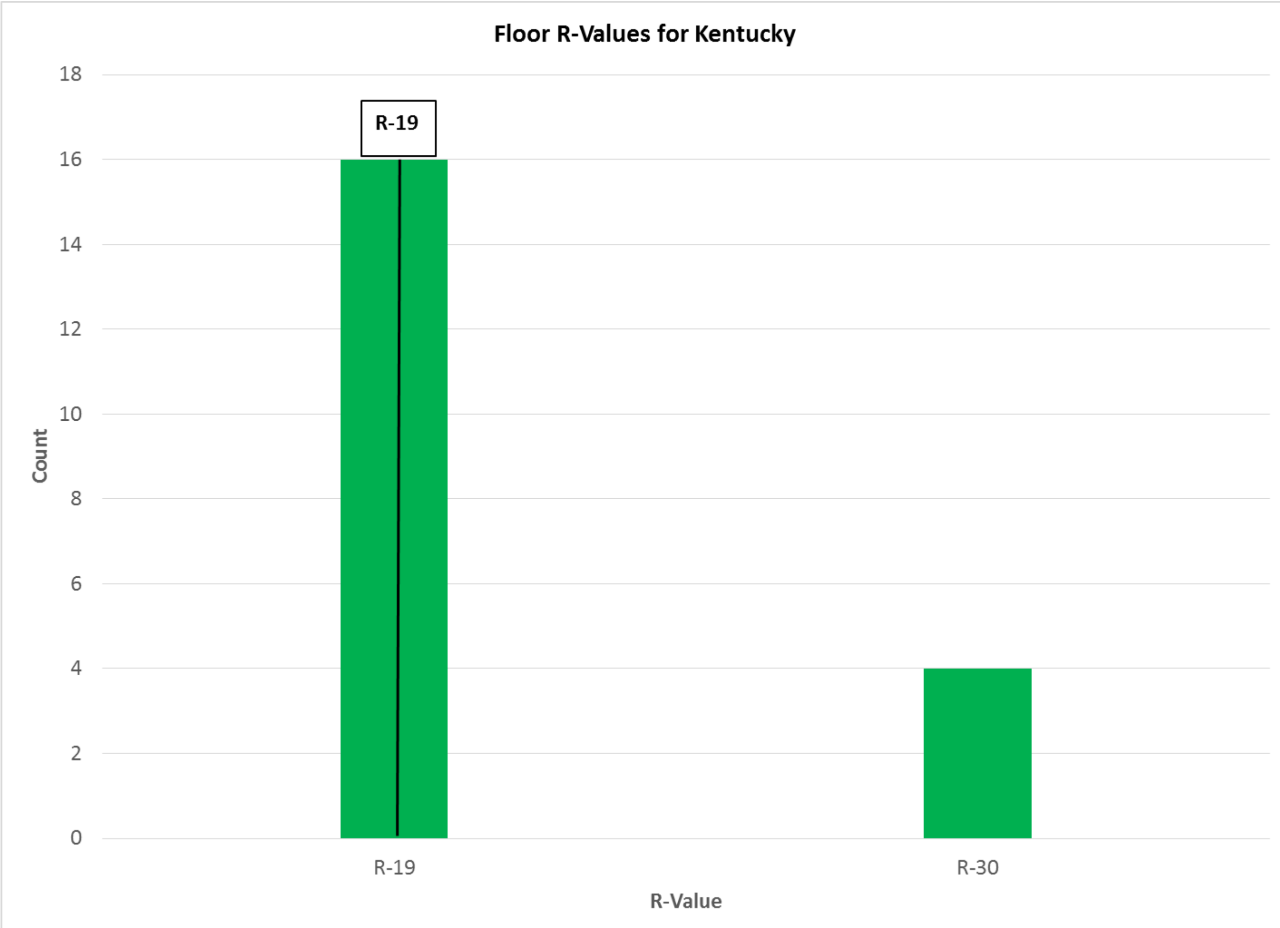

Figure 3.11. Floor R-Values for Kentucky

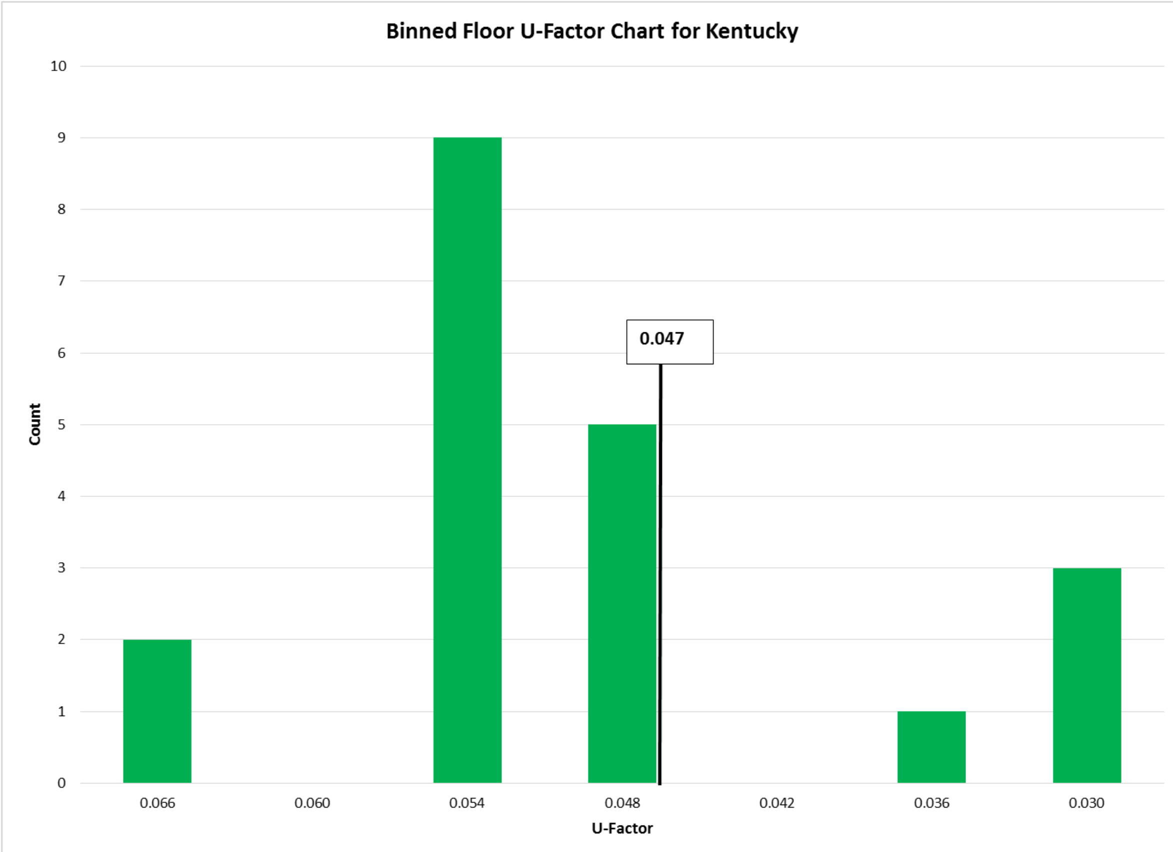

Figure 3.12. Floor Assembly Performance, including Insulation Installation Quality for Kentucky

- **Assembly U-Factor (expected):** U-0.047
- Observations:
  - Number: 20
  - Range: U-0.064 to U-0.032
  - Average: U-0.050
  - Rate: 4 of 20 (20%)
- Interpretations:
  - Cavity insulation is achieved at a high rate—all 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 insulation installation quality (Table 3.1).
  - While cavity insulation levels appear to be achieved successfully (R-value), the overall assembly performance (U-factor) exhibits room for improvement—this can be a focal point for future education and training activities in the state.

Slabs

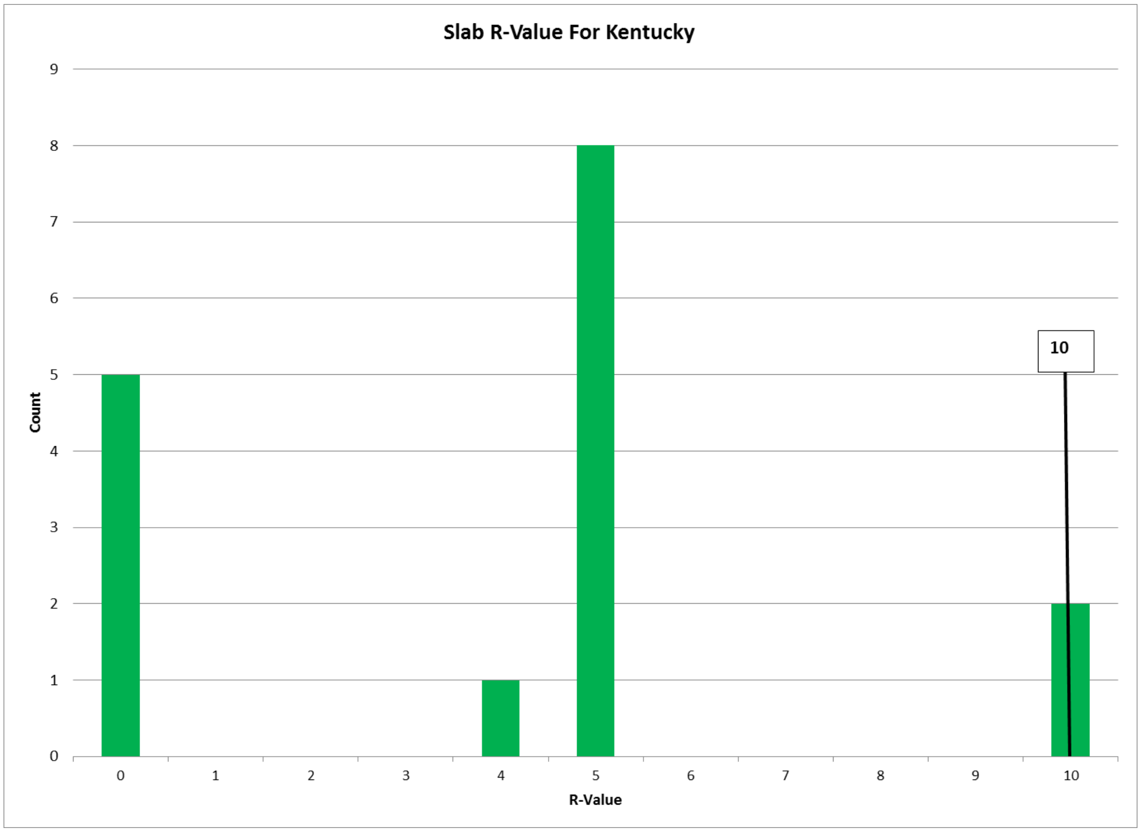

Figure 3.13. Slab R-Value for Kentucky

- **Requirement:** 10
- **Observations:**
  - Number: 16
  - Range: R-0 to R-10
  - Average: R-4
  - Compliance Rate: 2 of 10 (20 %)
- **Interpretations:**
  - The majority of slab edge insulation observations do not comply (80%), including several observations of no slab insulation.
  - Slab insulation should be considered an area for increased attention in future training and enforcement.

3.1.1.8 Duct Tightness

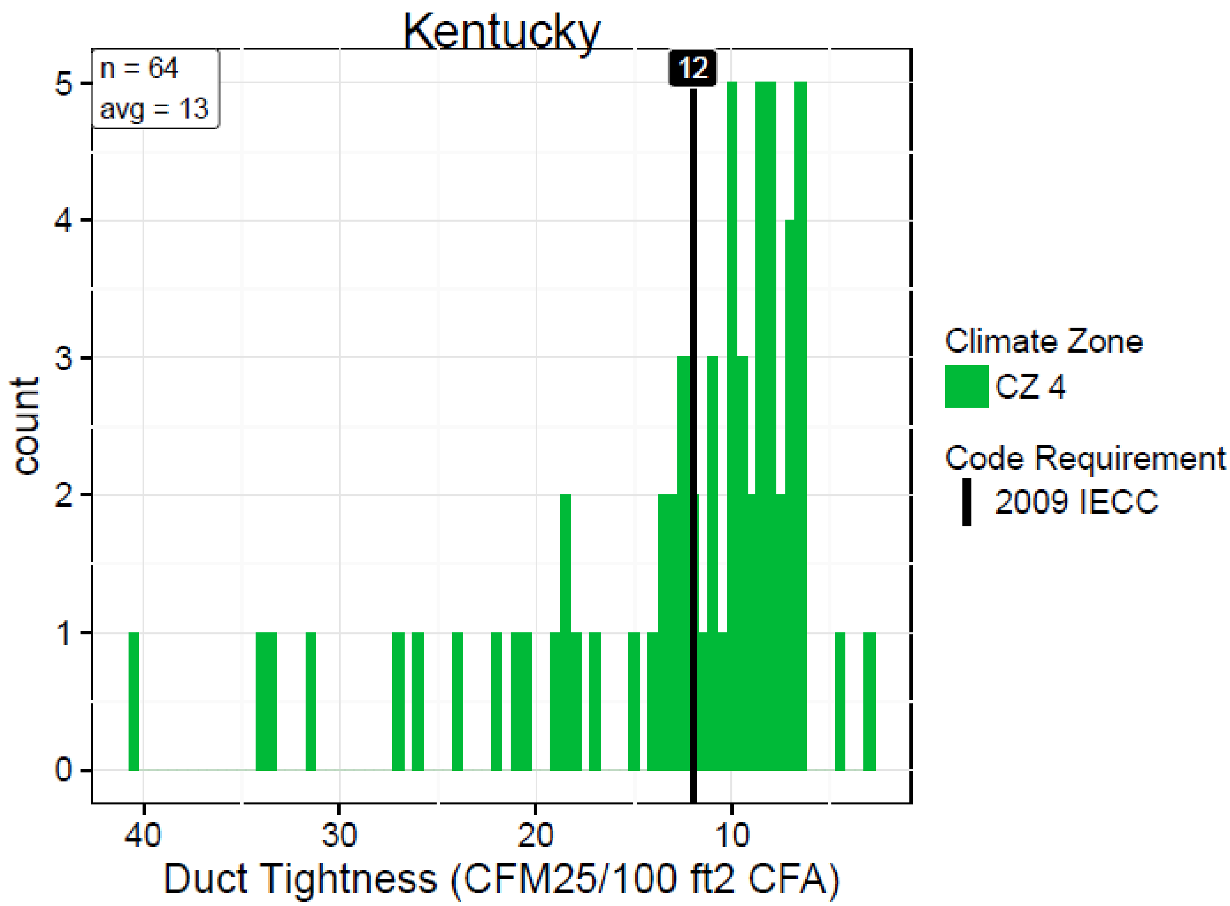

Figure 3.14. Duct Tightness (CFM25/100ft2 CFA)

- **Requirement**: 12 CFM25/100 ft^2 CFA
- **Observations:**
  - **Number**: 64 total; 40 with ducts not entirely in conditioned space
  - **Range**: 40.4 to 3.1
  - **Average**: 9.7 CFM25/100 ft^2 CFA (in unconditioned space); 18.5 for ducts 100% in conditioned space
  - **Compliance Rate**: 39 of 64 (61%) total; 31 of 40 (77%) for ducts not entirely in conditioned space
- **Interpretations:**
  - Overall the distribution exhibits higher leakage than expected compared to the current code requirement. There was also a large range of results.
  - Just over 60% of all observations meet the prescriptive requirement, with an average leakage of 12.99 CFM25/100 ft^2 CFA. However, 16 of the 25 observations that failed are for ducts that are

100% in conditioned space.[4] 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) represent an area for improvement within the state, and should be given increased attention in future training and enforcement.

Based on visual inspection, ducts were observed as sealed the majority of the time (81%). However, these observations yield a different conclusion relative to the duct leakage testing results from the state study. While the code requires ducts, air handlers and filter boxes to be sealed, it does not provide a comprehensive list of inspection points (as it does with envelope air sealing, in comparison), and it is therefore necessary to utilize sealing methods which are adequate in order to meet the required testing threshold. When comparing these visual results with the actual duct leakage testing results, it is clear that there can be significant differences in the two methods.

3.1.1.9 Impact of Insulation Installation Quality

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

Table 3.1 shows the insulation installation quality levels for framed envelope assemblies, as observed in the state. The majority of the observations (165 of 242) were classified as Grades II and III, indicating there is room for improvement in insulation installation quality.

Table 3.1. Insulation Installation Quality

Assembly	Grade I	Grade II	Grade III	Total Observations
Roof Cavity	34	47	5	**86**
Floor	8	10	2	**20**
Above Grade Wall	25	37	9	**71**
Basement Wall	5	23	2	**30**
Knee Wall	5	25	5	**35**

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

[4] There were 25 homes with ducts located entirely within conditioned space, and these ducts 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.
[5] See http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf

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.

3.1.2.1 Average Home

- Size: 2400 ft^2 and 1.3 stories

3.1.2.2 Compliance

- All homes were permitted under the 2009 IECC (100%)

3.1.2.3 Envelope

- **Profile:**
  - Walls: Majority were wood-framed walls with a mix of 4" (88%) and 6" (12%) studs
  - Foundations: Mix of basements (41%)[7], slab-on-grade (35%) and crawlspaces (24%)
- **Successes (percentage of compliant observations):**
  - Insulation labeled (85%)
  - Light fixtures sealed (100%)
  - Utility penetrations sealed (81%)
- **Areas for Improvement:**
  - Attic hatches & doors complied (60%)
  - Attic access openings sealed (41%)

3.1.2.4 Duct & Piping Systems

- **Profile:**
  - Supply and return ducts were located within conditioned space about half the time (percentage of duct system):
    - Supply: 48%
    - Return: 51%
  - About 40% of homes (53 homes) located *supply* ducts entirely within conditioned space
  - About 41% of homes (55 homes) located *return* ducts entirely within conditioned space

[6] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study.
[7] All basements observed in the study were conditioned.

– Duct Insulation (R-value): 7
– Pipe Insulation (R-value): 2.4

- **Successes:**
  – Building cavities not used as supply ducts (96%)
- **Areas for Improvement:**
  – Air handlers (13%) and filter boxes (5%) sealed

3.1.2.5 HVAC Equipment

- **Profile:**
  – Heating: Almost evenly split between electric furnaces and heat pumps with an average efficiency of 88 AFUE and 8.2 HSPF
  – Cooling: Mostly heat pumps with an average efficiency of 13 SEER
  – Water Heating: Mostly electric storage with an average capacity of 84 gallons and average efficiency rating of EF 0.91
  – Ventilation: Majority exhaust-only (91%) or AHU-integrated (7%). Approximately 98% of homes relied solely upon the bathroom fan—only 2% had a dedicated exhaust fan.
- **Successes:**
  – User manuals for mechanical systems provided (84%)

3.2 Energy Intensity

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

Analysis of the collected field data indicates an average regulated EUI (dashed line in Figure 3.15) of approximately 31.31 kBtu/ft^2-yr compared to 33.98 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements (black line in Figure 3.15). This suggests the EUI for a “typical” home in the state is about 7.8% better than code.

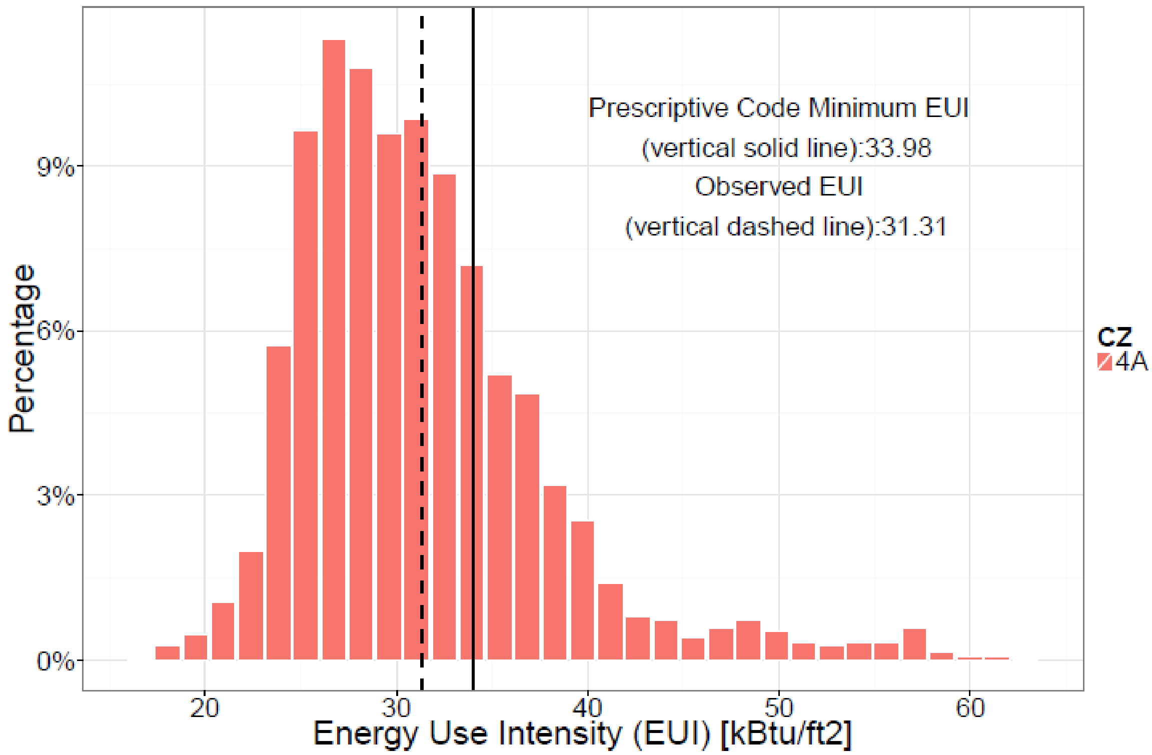

Figure 3.15. Statewide EUI Analysis for Kentucky

3.3 Savings Potential

Several key items exhibit the potential for improvement. Those with the greatest potential[8], shown below followed by the percent that met code, were analyzed further to calculate the associated savings potential, including energy, cost and carbon savings.

- Duct Leakage (77%[9]),
- Ceiling Insulation (59%)
- Envelope Air Leakage (70%),
- Lighting (31%),
- Exterior Wall Insulation (28%), and
- Foundations
  - Basement Wall Insulation (67%)
  - Floor Insulation (45%)
  - Slabs (20%).

For analytical details refer to Section 2.3.3 (Savings Analysis) or the methodology report (DOE 2016).

[8] Defined here as those with less than 85% of observations meeting the prescriptive code requirement
[9] This compliance rate is only for ducts that are not 100% in conditioned space

Estimated savings resulting from the analysis are shown below in order of highest to lowest total energy, cost and carbon savings (Table 3.2). As can be seen, there are significant savings opportunities, with the greatest total energy savings potential associated with these measures. In addition, Table 3.4 shows the total savings and emissions reductions that will accumulate over 5, 10, and 30 years of construction.

Table 3.2. Statewide Annual Measure-Level Savings for 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 Leakage	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 Leakage	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 3.3 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 3.3. 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 3.4. 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 Leakage	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 Leakage	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**

4.0 Conclusions

The Kentucky field study provides an enhanced understanding of statewide code implementation, and suggests that savings are available in the state through increased compliance with the Kentucky energy code. From a statewide perspective, the average home in Kentucky uses about 7.8% *less* energy than a home exactly meeting the state energy code. However, significant savings potential remains through increased compliance with targeted measures. Potential statewide annual energy savings are 62,508 MMBtu, which equates to $1,219,856 in cost savings, and emission reductions of 7,653 MT CO2e. Over a 30-year period, these impacts grow to over 29,000,000 MMBtu, $567 million, and over 3,500,000 MT CO2e in avoided emissions.

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

Table 4.1. Annual Statewide Savings Potential in Kentucky

		Annual Savings		
	Key Measure	**Energy** (MMBtu)	**Cost** ($)	**Carbon** (MT CO2e)
1	Envelope Air Leakage	27,182	484,314	3,092
2	Ceiling Insulation	11,372	215,656	1,080
3	Exterior Wall Insulation	9,277	171,044	1,102
4	Foundation Insulation	6,800	108,156	668
5	Lighting	5,742	197,544	1,427
6	Duct Leakage	2,135	43,142	284
Total		**62,508 MMBtu**	**$1,219,856**	**7,653 MT CO2e**

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 Development	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. State Sampling Plan

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

B.2 Substitutions

In the Kentucky study there were seven substitutions of original sample counties, 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

- Size (n=138): 2400 ft^2
- Number of Stories (n=138): 1.3

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

Conditioned Floor Area (ft^2)	< 1000	1000 to 1999	2000 to 2999	3000 to 3999	4000+
Percentage	0%	42%	32%	19%	7%

Table C.2. Number of Stories

No. of Stories	1	2	3	4+
Percentage	74%	28%	1%	0%

C.1.1.2 Wall Profile

- Framing Type (n=140):
  - *All* were framed construction (100%)
- Framing Material (n=139):
  - Wood (98%)

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

– Steel (2%)

- Framing Depth (n=138):
  - 4” (88%)
  - 6” (12%)
- Type of Wall Insulation (n=75)
  - Cavity Only (89%)
  - Cavity + Continuous (9%)
  - Continuous Only (1%)

C.1.1.3 Foundation Profile

- Foundation Type (n=140):
  - Basement (41%)
  - Slab on Grade (35%)
  - Crawlspace (24%)
- Basement Type (n=58):
  - Conditioned (100%)
  - Unconditioned (0%)

C.1.1.4 Builder Profile

- Average number of homes built annually (n=30): 135 homes

Table C.3. Number of Homes Built by Builder (annually)

No. of Homes per Year	< 10	10 to 50	50 to 99	100+
Percentage	20%	53%	0%	27%

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 (n=14):

Table C.4. Energy Code Used

Energy Code	2009 IECC
Percentage	100%

- Was the home participating in an above-code program (n=15)?
  - Yes (27%)—Half of these homes reported participation in the ENERGY STAR for Homes program and the other half were HERS homes.
  - No (73%)

C.1.3 Envelope

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

C.1.3.1 Insulation Labels

- Was insulation labeled (n=85)?
  - Yes (85%)
  - No (15%)

C.1.3.2 Ceilings

- Did the attic hatch/door exhibit the correct insulation value (n=55)?
  - Yes (40%)
  - No (60%)

C.1.3.3 Air Sealing[1]

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

- Thermal envelope sealed (n=78) (85%)
- Fenestration sealed (n=25) (84%)
- Openings around windows and doors sealed (n=75) (83%)
- Utility penetrations sealed (n=95) (81%)
- Dropped ceilings sealed (n=20) (90%)
- Knee walls sealed (n=24) (75%)
- Garage walls and ceilings sealed (n=57) (82%)
- Tubs and showers sealed (n=66) (70%)
- Attic access openings sealed (n=54) (41%)
- Rim joists sealed (n=69) (72%)
- Other sources of infiltration sealed (n=81) (79%)
- IC-rated light fixtures sealed (n=65) (100%)

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

C.1.4 Duct & Piping Systems

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

C.1.4.1 System Profile

- Duct Location in Conditioned Space (average percentage):
  - Supply (n= 133): 48%
  - Return (n= 133): 51%
- Ducts Entirely Within Conditioned Space (number and percentage)
  - Supply: 53 homes (40%)
  - Return: 55 homes (41%)
- Duct in Unconditioned Space Insulation (R-value):
  - Supply (n=25): 7.3
  - Return (n=21): 6.7
- Ducts in Attics (R-value):
  - Supply (n=58): 7.7
  - Return (n=63): 7.1
- Pipe Insulation (R-value):
  - Average value of R-2.4, mix of R-2 and R-3 (n=105)
- Building cavities used as supply ducts (n=98) (4%)
- Air ducts sealed (n=91) (81%)
- Air handlers sealed (n=110) (87%)
- Filter boxes sealed (n=100) (85%)

C.1.5 HVAC Equipment

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

C.1.5.1 Heating

- Fuel Source (n=127):
  - Gas (44%)
  - Electricity (56%)
- System Type (n=117):
  - Furnace (51%)
  - Heat Pump (48%)
  - Electric Resistance (1%)

- Average System Capacity (n=112):
  - Furnace: 59,600 Btu/hr
  - Heat Pump: 39,000 Btu/hr
  - Electric Resistance: 48,000 Btu/hr
- Average System Efficiency (n=81):
  - Furnace: 88 AFUE (*all* observed furnaces had an efficiency of 80 AFUE or better)
  - Heat Pump: 8.2 HSPF

C.1.5.2 Cooling

- System Type (n=94):
  - Central AC (31%)
  - Heat Pump (69%)
- Average System Capacity (n=89):
  - Central AC: 40,000 Btu/hr
  - Heat Pump: 38,000 Btu/hr
- Average System Efficiency (n=59):
  - 13.7 SEER (observations ranged from 13 to 18 SEER)

C.1.5.3 Water Heating

- Fuel Source (n=94):
  - Gas (31%)
  - Electric (68%)
  - Wood (1%)
- System Type (n=83):
  - Storage (84%)
  - Tankless (16%)
- System Capacity (n= 65):
  - Average Storage 54 gallons (observations ranged from 40 to160 gallons)

Table C.5. Water Heating System Storage Capacity Distribution

Capacity	< 50 gal	50-59 gal	60-69 gal	70-79 gal	80-89 gal	90+ gal
Percentage	2%	86%	3%	2%	6%	2%

- Average System Efficiency (n=81):
  - Electric Storage (non-heat pump): EF 0.91
  - Electric Storage (heat pump): EF 6.25

- Gas Storage: No observations of efficiency
- Gas Tankless: EF 0.89

C.1.5.4 Ventilation

- System Type (n=123):
  - Exhaust Only (91%)
  - AHU-Integrated (7%)
  - Standalone ERV/HRV (2%)
- Exhaust Fan Type (n=111):
  - Dedicated Exhaust (2%)
  - Bathroom Fan (98%)

C.1.5.5 Other

- Mechanical manuals provided (n=77) (84%)

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