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Pennsylvania Residential Energy Code Field Study: Baseline Report

May 2017

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J Hathaway
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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 Pennsylvania 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 October 2014 and continued through July 2015. During this period, research teams visited 171 homes during various stages of construction, resulting in a substantial data set based on observations made directly in the field. Analysis of the data has led to a better understanding of the energy features present in homes, and indicates over $2.7 million in potential annual savings to Pennsylvania homeowners that could result from increased compliance with the 2009 International Energy Conservation Code (and equivalent compliance options). 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 Performance Systems Development (PSD). 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, and are intended to inform future energy code education, training and outreach activities.

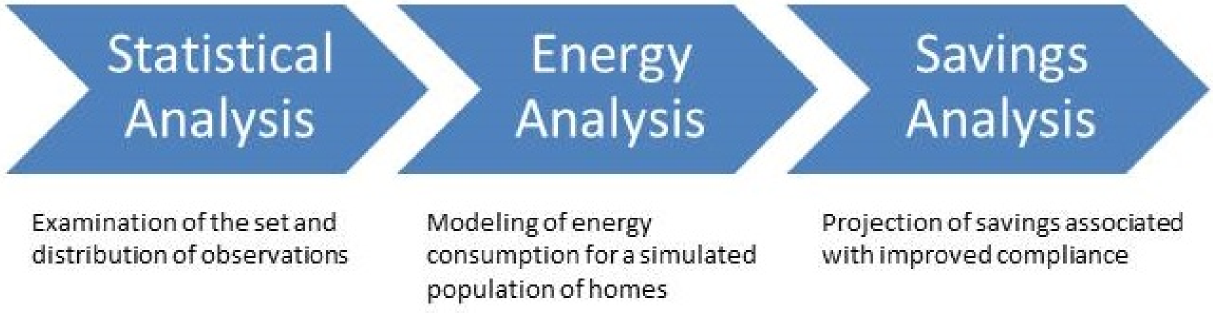

Figure ES.1. Stages of Analysis Applied in the Study

Results

The key items with the greatest potential for savings in Pennsylvania 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 Pennsylvania

Measure	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Duct Leakage	86,553	1,360,493	6,363
Exterior Wall Insulation	54,594	798,031	3,710
Foundation Insulation	17,711	175,611	802
Lighting	4,868	365,254	1,760
TOTAL	**163,726 MMBtu**	**$2,699,388**	**12,635 MT CO2e**

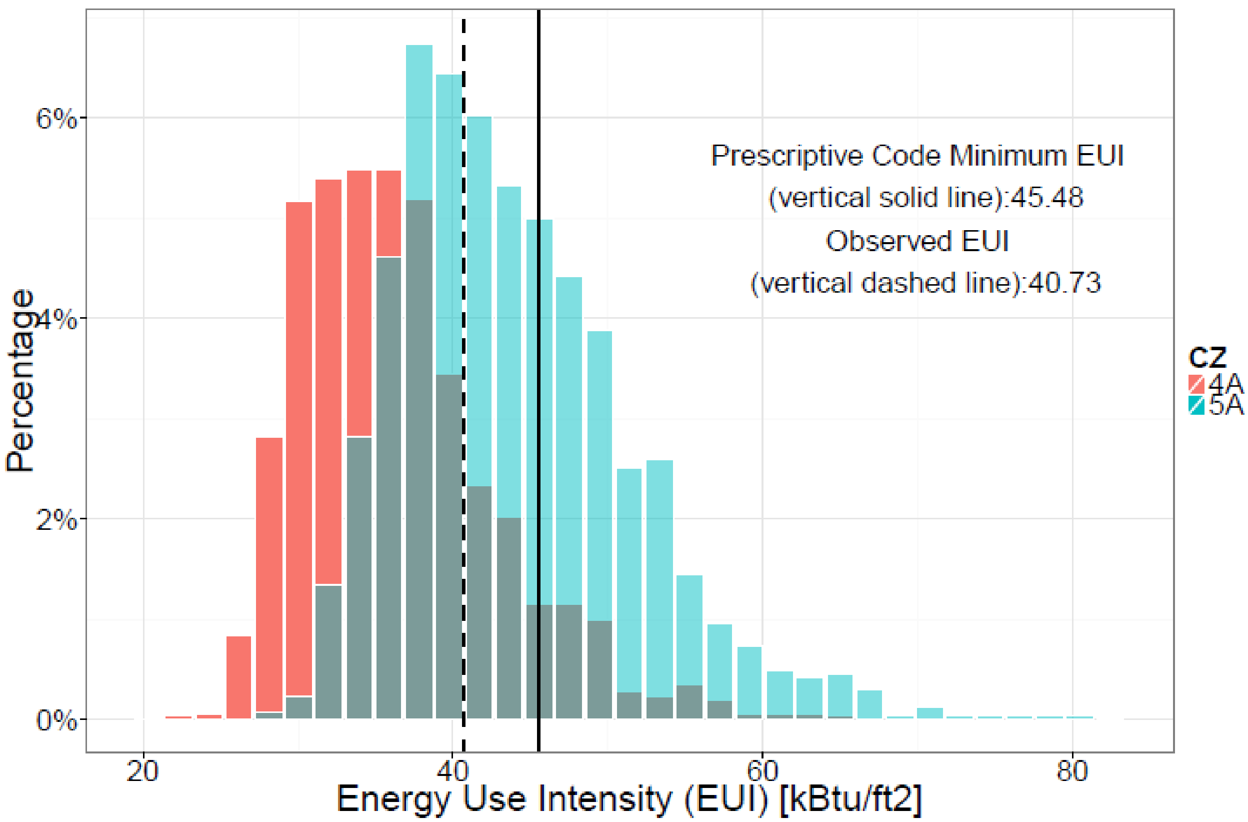

Figure ES.2. Modeled distribution of regulated EUI (kBtu/ft^2/year) in Pennsylvania

In terms of overall energy consumption, the analysis shows that home within the state use *less* energy than would be expected relative to homes built to the current minimum state code requirements (Figure ES.2). Analysis of the collected field data indicates average regulated energy use intensity (EUI) of 40.73 kBtu/ft^2-yr statewide compared to 45.48 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements. This suggests that on average the typical home in the state is about 10% better than code.

Note that in an EUI analysis, items found to be better than code offset savings from items found to be worse than code. These below-code items represent a savings opportunity regardless of the above-code items. In this study, a significant portion of homes were found to not meet code in several key areas impacting energy use, durability, and comfort. Thus, there is still a significant energy savings opportunity ($2.7 million annually) from energy code compliance enhancement activities in Pennsylvania.

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The following members comprised the Pennsylvania project team:

- Mike Turns, *Performance Systems Development*
- Susan Mann, *Performance Systems Development*
- Lauren McFeeley, *Performance Systems Development*
- Jim Phelps¸ *Performance Systems Development*
- PSD's team of field specialists

The PSD team also wishes to acknowledge PECO – Exelon Company and PPL Electric Utilities, who generously provided a portion of the cost share for this project.

Thanks also to the following organizations for their support of the project:

- The Pennsylvania Department of Environmental Protection (DEP),
- The Pennsylvania Department of Community and Economic Development (DCED),
- The Pennsylvania Construction Codes Academy (PCCA)
- The Pennsylvania Building Officials Conference (PENNBOC) and its local chapters,
- The Pennsylvania Association of Building Code Officials (PABCO),
- Lancaster County Code Officials (LanCode)
- The Pennsylvania Association of Code Officials (PACO), and
- The ICC Liberty Chapter of Philadelphia

Performance Systems Development (PSD)

PSD is a technology-enabled energy efficiency program implementation firm with offices throughout the Northeast and Mid-Atlantic, and clients across the country. PSD's team of building scientists, energy engineers, program and project managers, and software developers work with a wide range of clients to design, deliver and support utility-funded residential new construction programs, energy code training and code compliance enhancement programs, and operate 3rd party Quality Assurance (QA) programs for residential, multifamily and commercial programs. PSD is a RESNET-accredited training provider, BPI training affiliate, and HERS Rating Provider. PSD's industry-leading program management software platform, Compass, is utilized to track, manage and report on energy savings activities in over 30 programs across the country. More information on PSD is available at http://www.psdconsulting.com.

Acronyms and Abbreviations

AC	air conditioning
ACCA	Air Conditioning Contractors of America
ACH	air changes per hour
AFUE	annual fuel utilization efficiency
AIA	American Institute of Architects
Btu	British thermal unit
cfm	cubic feet per minute
CZ	climate zone
DCED	Department of Community & Economic Development
DEP	Department of Environmental Protection
DLI	Department of Labor & Industry
DOE	U.S. Department of Energy
EDC	electric distribution company
EERE	Office of Energy Efficiency and Renewable Energy
EUI	energy use intensity
FOA	funding opportunity announcement
HERS	home energy rating system
HSPF	heating season performance factor
ICC	International Code Council
IECC	International Energy Conservation Code
kBtu	thousand British thermal units
MMBtu	million British thermal units
NA	not applicable
NEEP	Northeast Energy Efficiency Partnerships
PA	Pennsylvania
PABCO	Pennsylvania Association of Building Code Officials
PBA	Pennsylvania Builders Association
PCCA	Pennsylvania Construction Codes Academy
PENNBOC	Pennsylvania Building Code Officials Conference
PHRC	Pennsylvania Housing Research Center
PNNL	Pacific Northwest National Laboratory
PSD	Performance Systems Development
PUC	Public Utility Commission
RFI	request for information
SHGC	solar heat gain coefficient
TSD	technical support document

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1.0 Introduction

A research project in the Commonwealth of Pennsylvania investigated the energy code-related aspects of unoccupied, newly constructed, single family homes across eastern Pennsylvania, with savings impacts extrapolated to the rest of 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 Pennsylvania field study was initiated in October 2014 and continued through July 2015. During this period, research teams visited 171 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), 2009 International Residential Code – Chapter 11, and Pennsylvania's Alternative Residential Energy Provisions; all of which are essentially equivalent. 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]

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[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

1.2 Project Team

The Pennsylvania project and field data collection were led by Performance Systems Development (PSD). 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, and often have direction from state regulatory bodies (e.g., the public utility commission) to achieve energy savings. Many utilities have expressed an increasing interest in energy code investments, and are looking at energy code compliance as a means to provide assistance and generate additional savings. The field study is aimed specifically at providing a strong, empirically-based case for such utility investment.

2.0 Methodology

2.1 Overview

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

Highlights of the methodology:

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

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

1. Envelope tightness (ACH at 50 Pascals)
2. Windows (U-factor & SHGC)
3. Wall insulation (assembly U-factor)
4. Ceiling insulation (R-value)
5. Lighting (% high-efficacy)
6. Foundation insulation (R-value)[2]
7. Duct tightness (expressed in 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 Pennsylvania study, including sampling, data collection, and resulting data analysis. More information on the full DOE protocol is published separately from this report (DOE 2016a). Further details on the PNNL analysis are

[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 were combined into a single category of foundation insulation.

also available in a technical support document (TSD) (DOE 2016b) and are available on the DOE Building Energy Codes Program website.[3]

2.2 State Study

The prescribed methodology was customized for Pennsylvania 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

Pennsylvania has over 2,500 permit-issuing jurisdictions (Census places). For this reason, DOE and PSD made the decision to limit the project coverage area to the eastern half of the state. In the project coverage area, there are still over 1,000 permit issuing jurisdictions. Since one of the goals of the project is to encourage utility investment in codes support programs, the project coverage area was aligned with the three major electric distribution companies in the area: Metropolitan-Edison (Met-Ed), PECO, and PPL. This coverage area includes all three climate zones found in Pennsylvania (CZ4, CZ5, CZ6). No sample homes were located in CZ6 because of limited permit activity, and relatively few homes are built in CZ6 anywhere in the state. Thus, the area is representative of the rest of the state in terms of energy code requirements. The coverage area comprises a wide range of permit-issuing jurisdictions including the major urban, suburban, and rural areas and was considered to be generally representative of the state as a whole. Municipalities included in the sample also comprised a wide range of building department and builder sizes.

Figure 2.1. Program Coverage Area

PNNL developed a project coverage area-wide, statistically representative sampling plan based on the average of the three most recent years of Census Bureau permit data[4]. The samples were apportioned to jurisdictions across the project coverage area in proportion to their average level of construction compared to the overall construction activity in the project coverage area. This approach is a known as a proportional random sample. The plan specified the number of key item observations required in each selected jurisdiction (totaling 63 of each key item across the entire project coverage area).

[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)

An initial sample plan was first developed by PNNL, and then vetted by stakeholders within the state. Stakeholders agreed that the project coverage area could reasonably be used to extrapolate the findings to the entire state. Special considerations were discussed by stakeholders at a project kickoff meeting, such as state-specific construction practices and systematic differences across county or climate zone 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 project team began contacting local building departments to identify homes currently in the permitting process. Code officials responded by providing lists of homes at various stages of construction within their jurisdiction. These lists were then sorted using a random number generator and utilized by the team's field personnel to contact builders to gain site access. 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[5]. The final data collection form is available in spreadsheet format on the DOE Building Energy Codes Program website[6]. The form included all energy code requirements (i.e., not just the eight key items), as well as additional items required under the prescribed methodology. For example, the field teams were required to conduct a blower door test and duct 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 was used to modify that key item during the energy modeling and savings calculation. Equipment, including 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

[5] Pennsylvania Alternative option requirements for Lighting were also included.
[6] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study and based on the forms typically used by the RES*check* compliance software.
[7] See http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf

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.

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

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

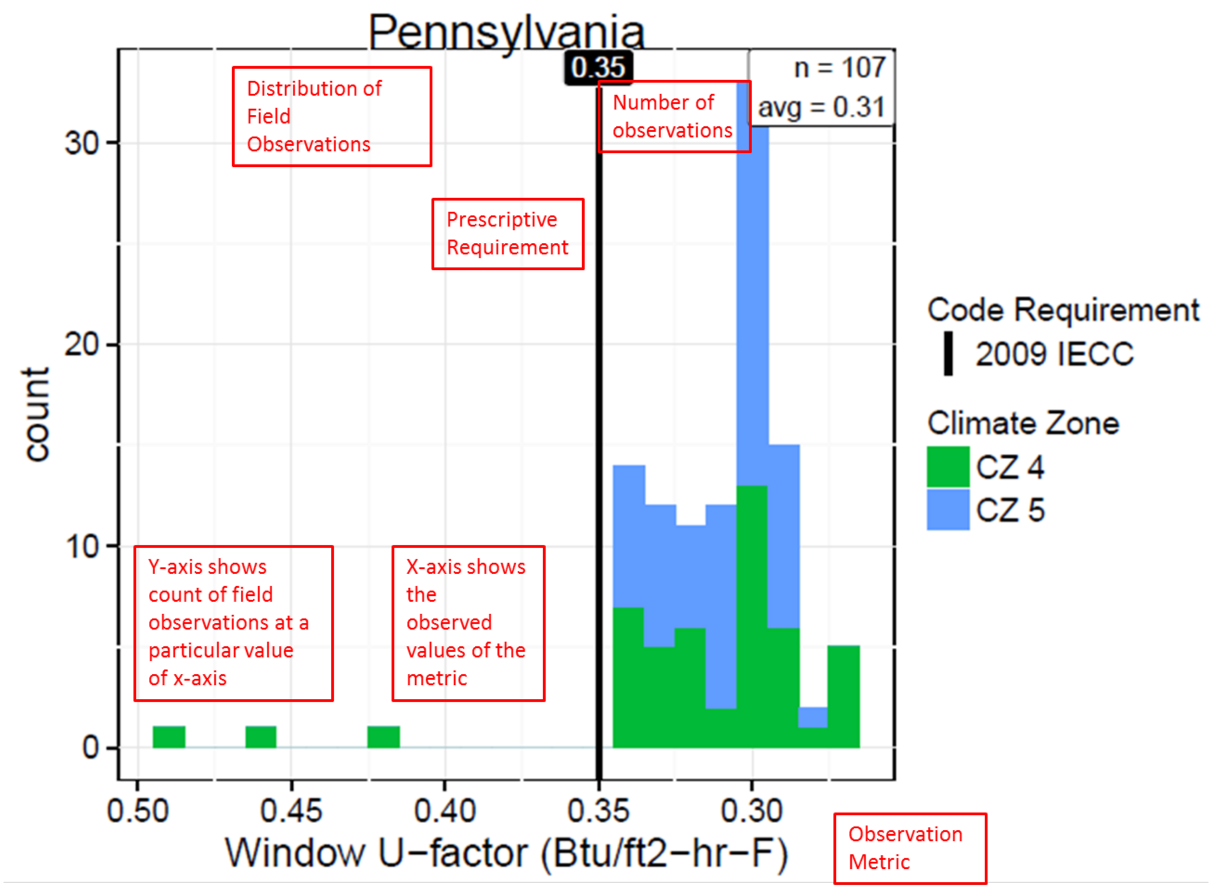

Figure 2.2. Sample Graph

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 climate zone 4 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.

For walls and foundations, two graphs are included – one for R-value observations and another for U-factor observations. The R-value graphs show whether or not homes are being constructed with the required amount of insulation for the climate zone. The U-factor graphs indicate whether or not the combination of installed R-value and insulation installation quality meets the U-factor requirements in the climate zone. The combination of these two graphs can be used to determine if there is an issue with the amount of insulation, insulation installation quality, or both.

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 TSD (DOE 2016b).[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]. This was done by individually upgrading each worse-than-code observation to the corresponding *prescriptive* code requirement, resulting in a second set of models (*full compliance*) that could be compared to the first (*as-built*). All other components were maintained at the corresponding prescriptive code value, allowing for the savings potential associated with a key item to be evaluated in isolation.

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

[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.

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.

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 of interest, such as analysis based on climate zone level, or reporting of non-key items, were identified. 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

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.

When the sample plans were developed, the methodology assumed that each Census Bureau place had a unique name within a state. After data collection had already begun, it was discovered that this was not the case (e.g., there are multiple municipalities named Penn Township). This resulted in the sample plan inadvertently requiring visits in a number of municipalities that did not have adequate numbers of homes under construction. To address this issue, some substitutions were made within the original sampling plan, as shown 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. Pennsylvania comprises multiple climate zones, but samples were only taken from Climate Zones 4A and 5A in eastern Pennsylvania. Climate Zone 6A was not sampled as the construction activity in that climate zone did not appear to be significant. A discussion of other findings is also covered in this section, including a description of how certain observations, such as insulation installation quality, are used to modify key items. (See Section 2.3.1 for a sample graph and explanation of how they should be interpreted.)

3.1.1 Key Items

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

The following key items were found applicable within the state:

1. Envelope tightness (ACH at 50 Pascals)
2. Window SHGC
3. Window U-factor
4. Exterior wall insulation (assembly U-factor)
5. Ceiling insulation (R-value)
6. Lighting (% high-efficacy)
7. Foundations – basement walls and floors (assembly U-factor)
8. Duct tightness (expressed in cfm per 100 ft^2 of conditioned floor area at 25 Pascals)

The two main foundation types observed were heated basements and floors over unheated basements. In addition, there were seven slab observations, but due to that small number, graphics are only provided for heated basements and floors above the unheated basements.

3.1.1.1 Envelope Tightness

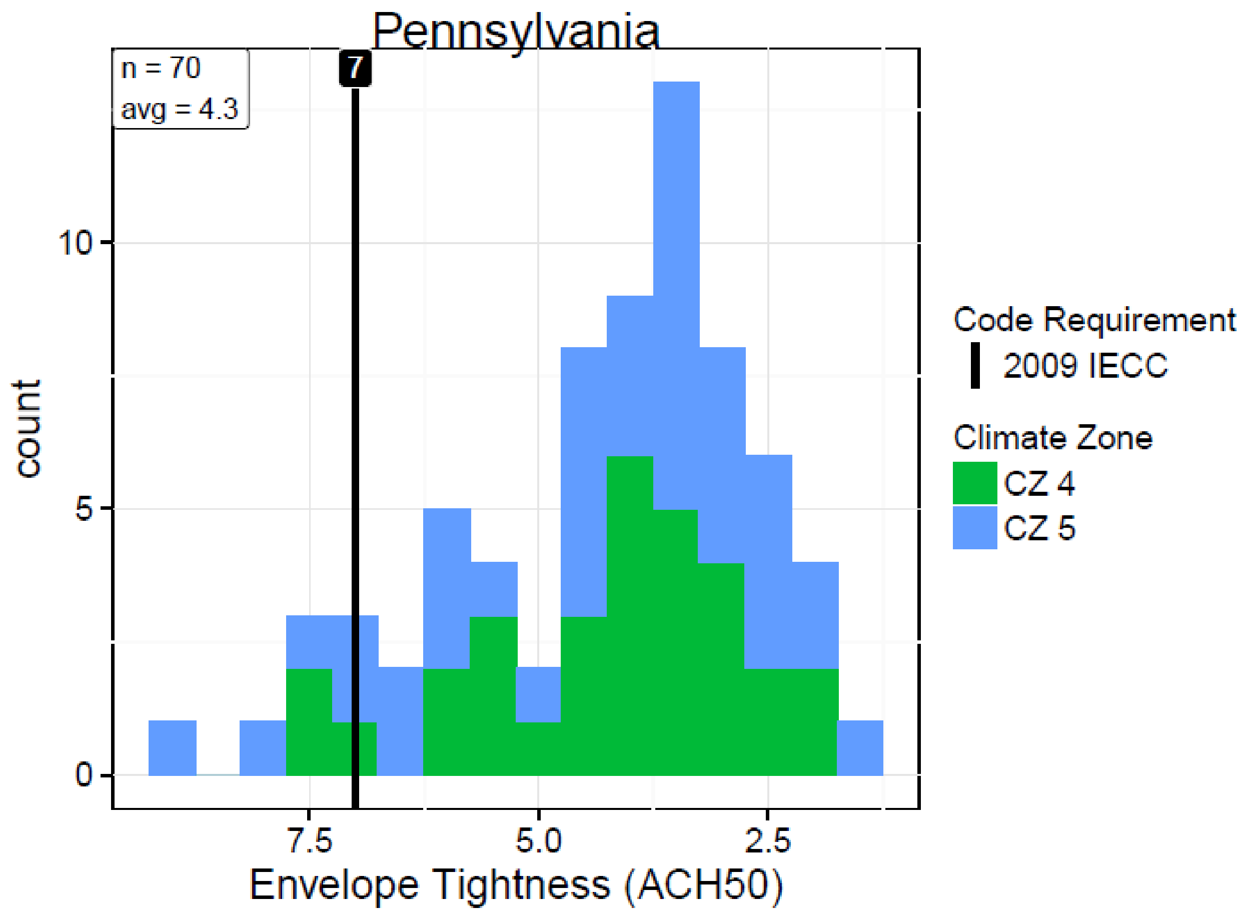

Figure 3.1. Envelope Tightness (ACH50)

Table 3.1. Envelope Tightness (ACH50)

Climate Zone	CZ4	CZ5	Statewide
Number	31	39	70
Range	7.59 to 1.88	1.71 to 8.85	8.85 to 1.71
Average	4.3	4.4	4.3
Requirement	7	7	7
Compliance Rate	29 of 31 (94%)	36 of 39 (92%)	65 of 70 (93%)

- **Interpretations:**
  - Overall, the distribution exhibits significantly lower air leakage than expected based on the current code requirement.
  - Nearly all the observations met or exceeded the prescriptive code requirement, and all of the remaining observations were in the 7.4 to 8.8 ACH50 range.

The project team reported that many homes were found not to have mechanical ventilation installed despite their relatively low infiltration rates.

3.1.1.2 Window SHGC

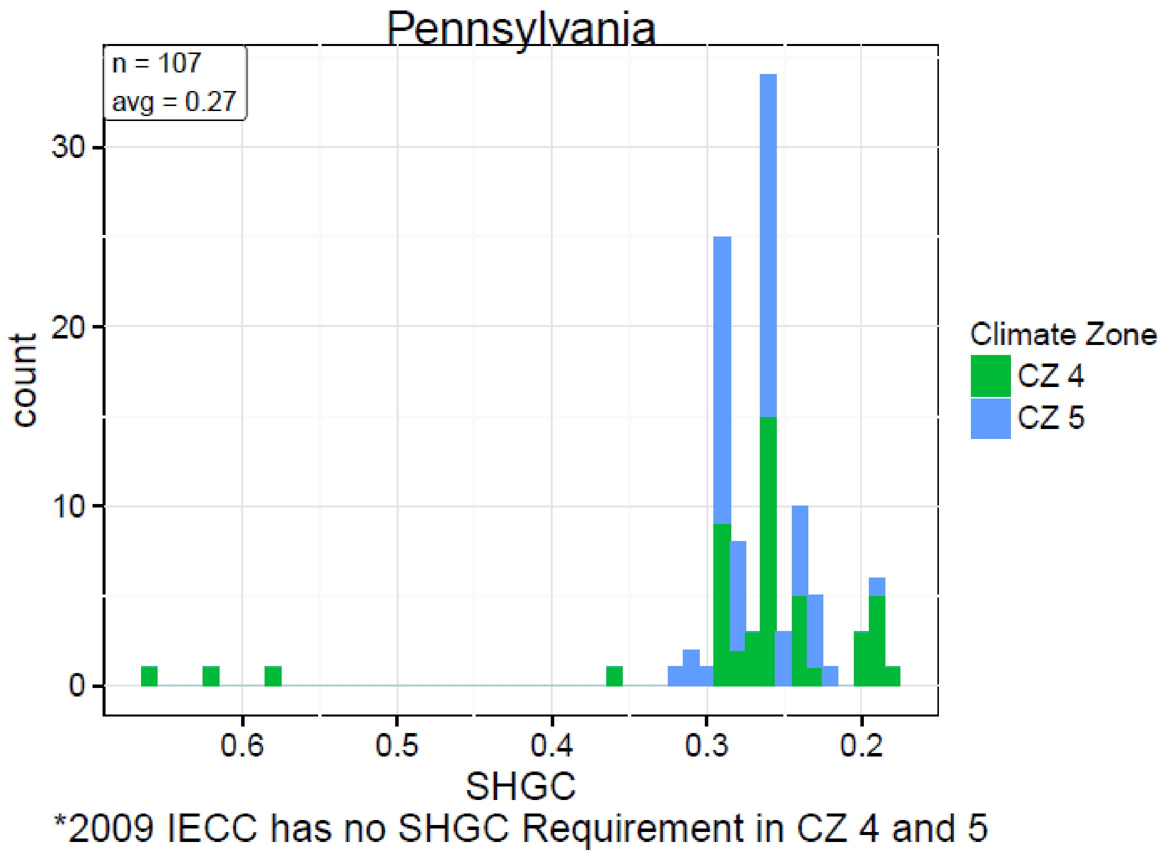

Figure 3.2. Window SHGC

Table 3.2. Window SHGC

Climate Zone	CZ4	CZ5	Statewide
Number	48	59	107
Range	0.66 to 0.18	0.32 to 0.19	0.66 to 0.18
Average	0.28	0.27	0.27
Requirement	NA	NA	NA
Compliance Rate	NA	NA	NA

- **Interpretations:**
  - SHGC values were very consistent, and nearly meet the prescriptive requirement for Climate Zones 1-3, even though there are no SHGC requirements in Climate Zones 4 and 5.
  - The vast majority of the observations were in the 0.22 to 0.31 SHGC range.

3.1.1.3 Window U-Factor

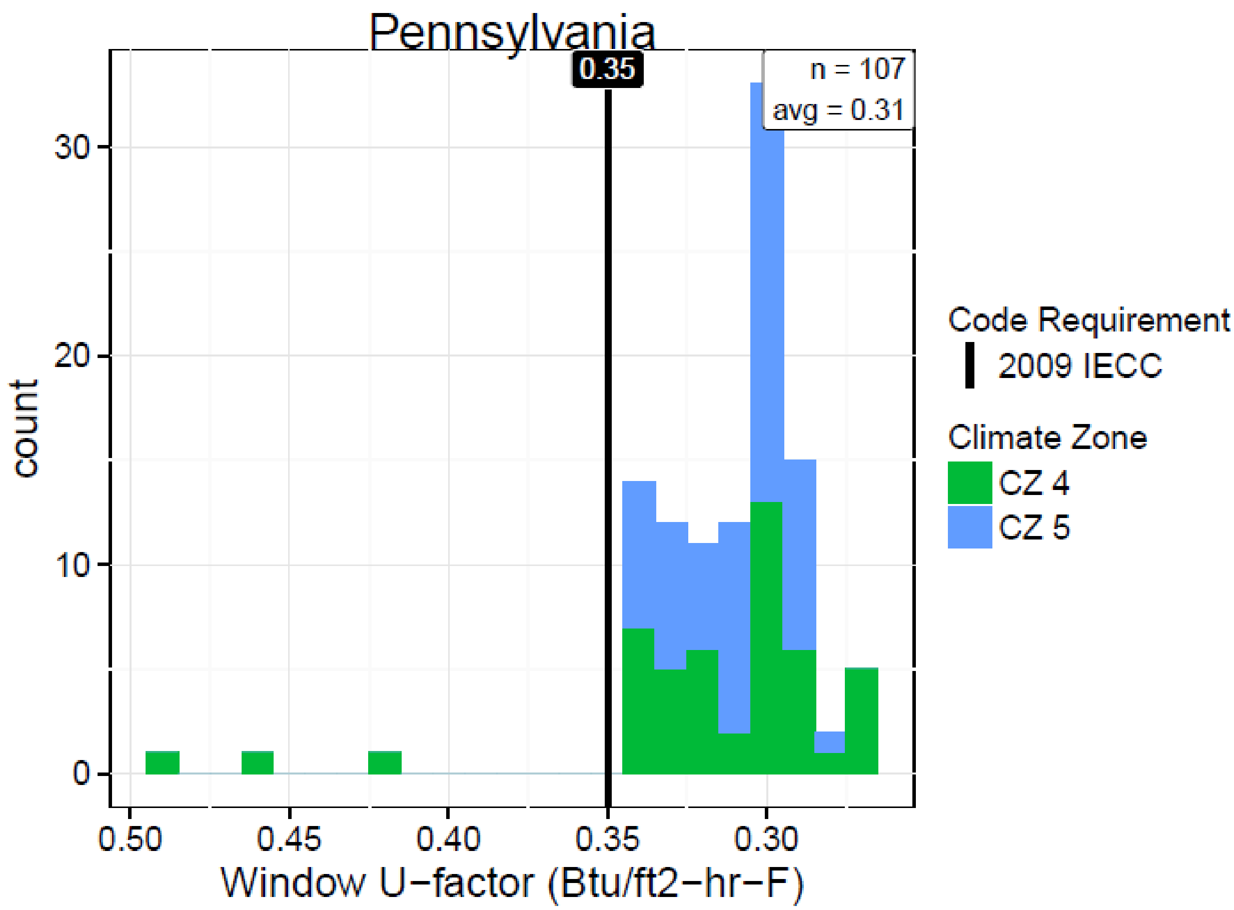

Figure 3.3. Window U-Factor

Table 3.3. Window U-Factor

Climate Zone	CZ4	CZ5	Statewide
Number	48	59	107
Range	0.49 to 0.27	0.34 to 0.28	0.49 to 0.27
Average	0.32	0.31	0.31
Requirement	0.35	0.35	0.35
Compliance Rate	45 of 48 (94%)	59 of 59 (100%)	104 of 107 (97%)

- **Interpretations:**
  - There is an extremely high rate of compliance for fenestration products.
  - 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.

3.1.1.4 Wall Insulation

Two graphs are shown for each climate zone for walls, cavity and continuous insulation (R-value) and binned wall assembly (U-factor). The R-value graphs show both the cavity and continuous insulation R-values observed, sorted in order of increasing cavity insulation R-value. The binned U-factor graphs indicate the U-factor of the wall 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.

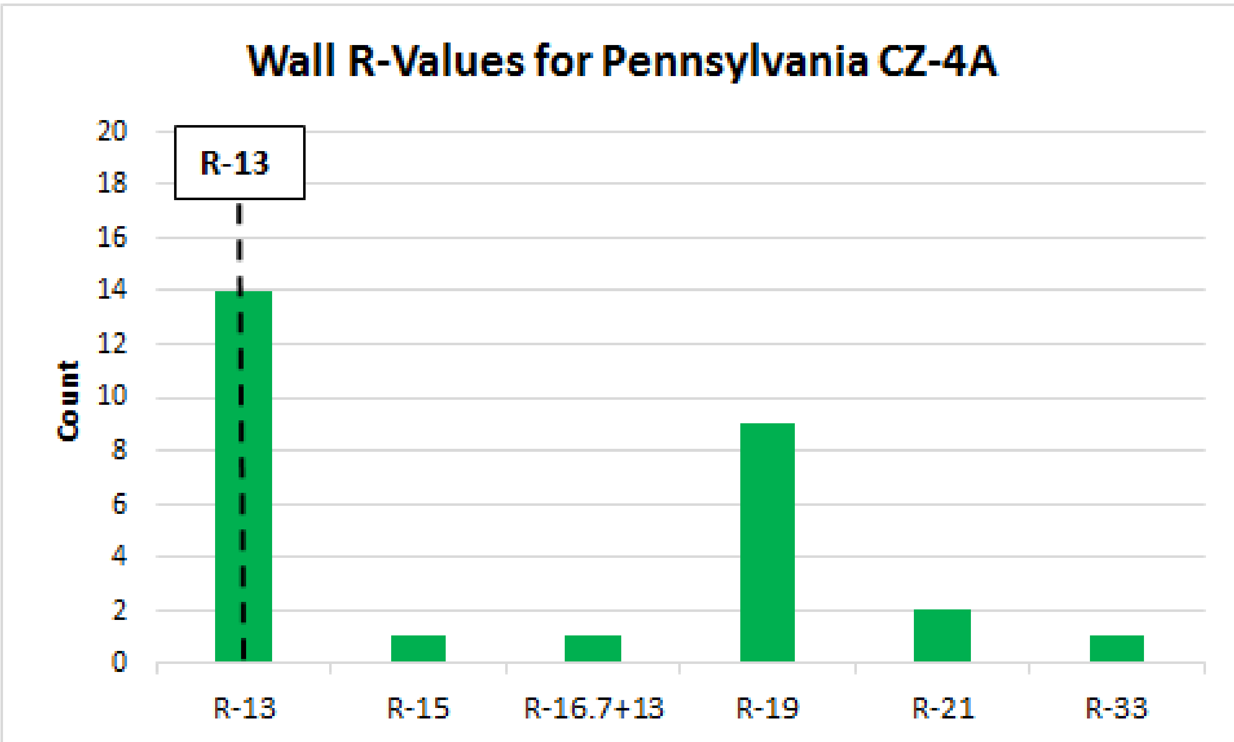

Figure 3.4. Wall R-Values in Pennsylvania CZ4A

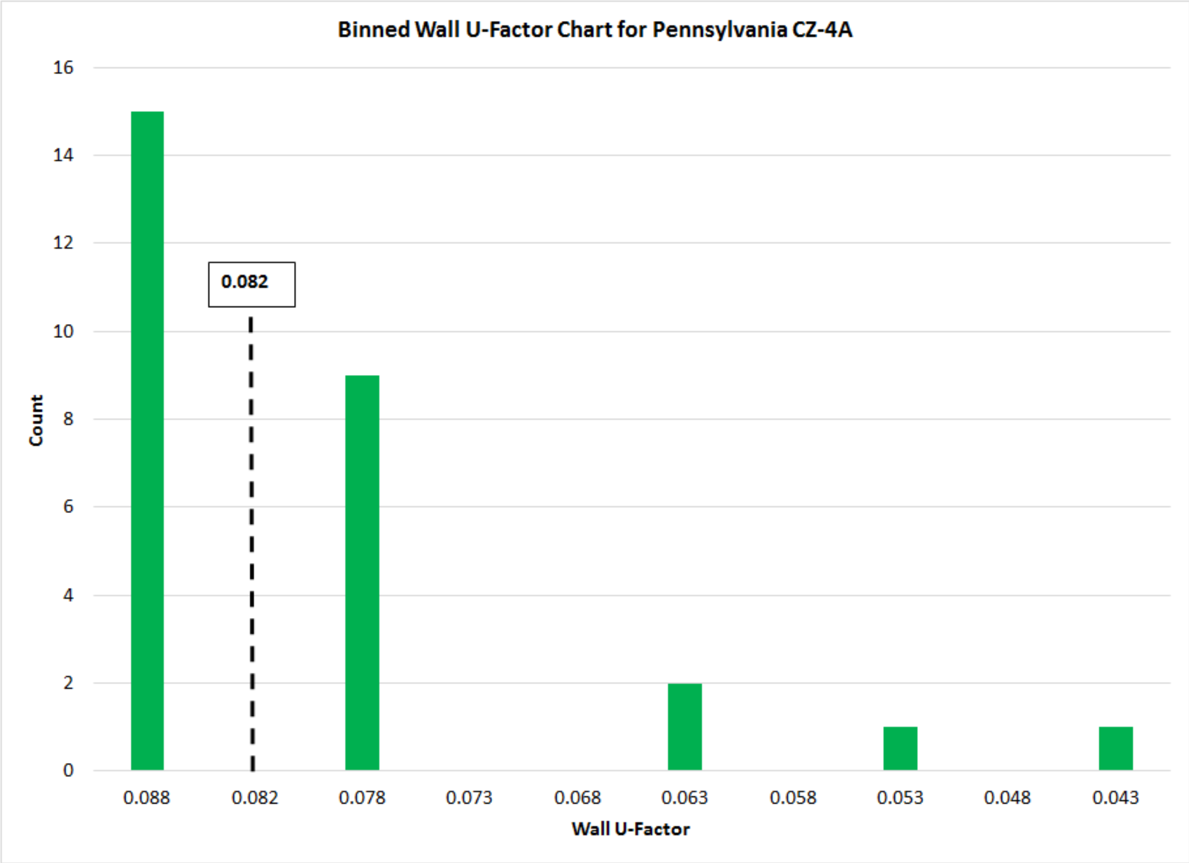

Figure 3.5. Wall Assembly Performance, including Wall Insulation Installation Quality

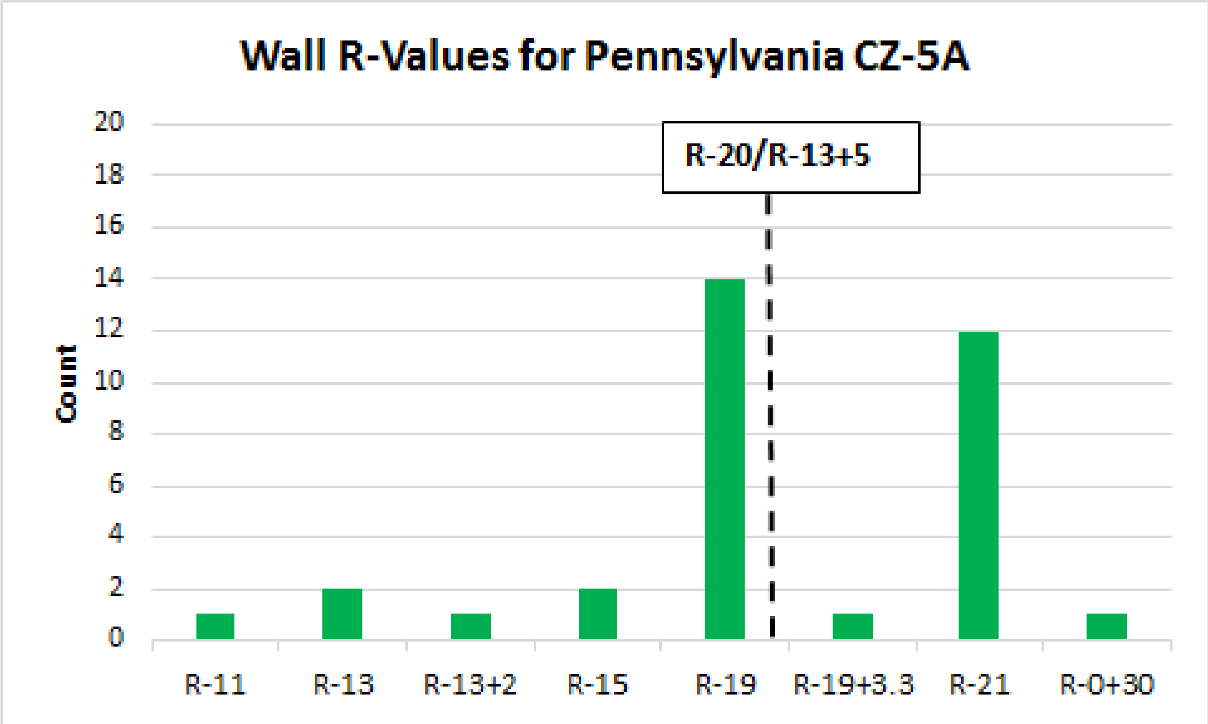

Figure 3.6. Wall-R-Values in Pennsylvania CZ5A

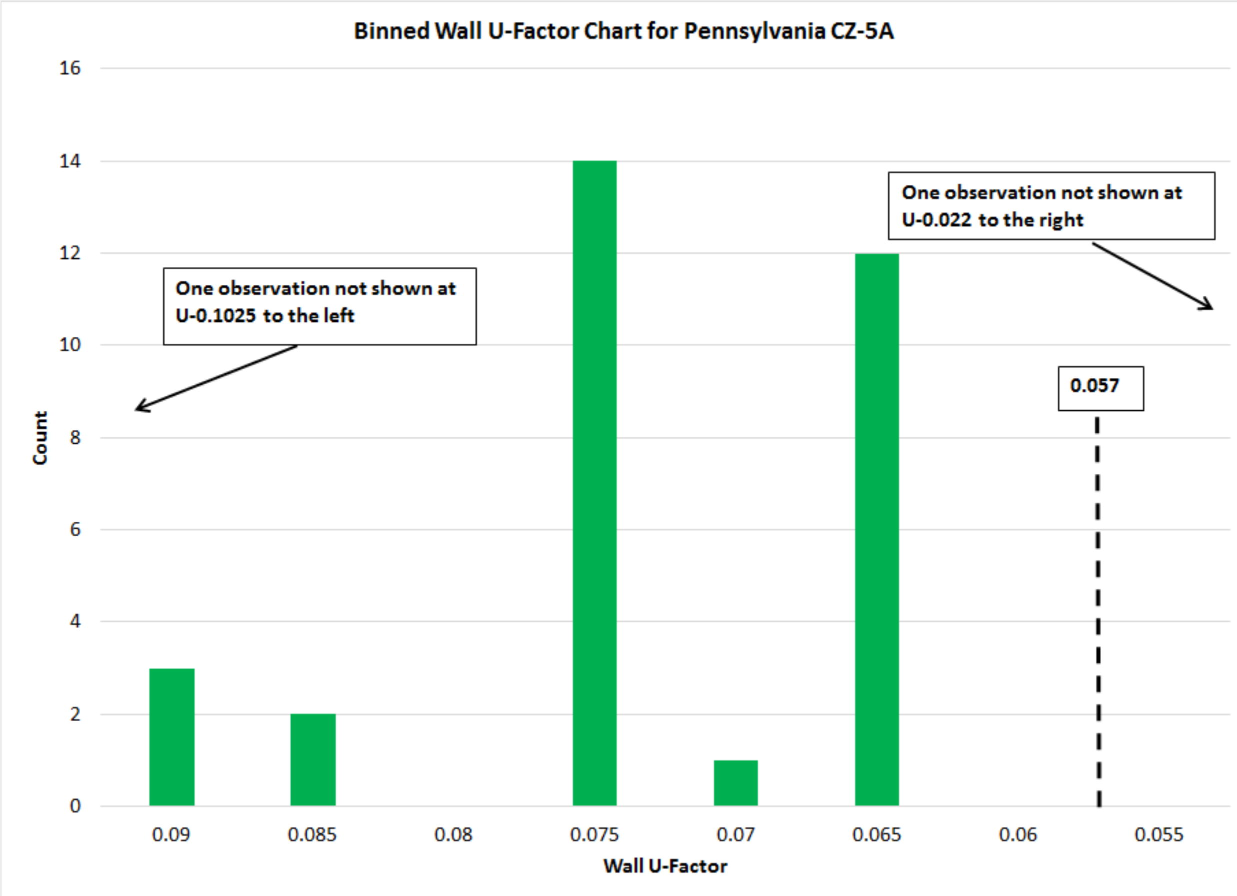

Figure 3.7. Wall Assembly Performance, including Wall Insulation Installation Quality*

*Note: two extreme U-factors in CZ5 were dropped from the graph to allow more detailed display of the distribution of observations.

Table 3.4. Wall U-Factor, including Wall Insulation Installation Quality

Climate Zone	CZ4	CZ5	Statewide
Number	28	34	62
Range	0.082 to 0.043	0.105 to 0.020	0.105 to 0.020
Average	0.080	0.072	0.076
Assembly U-Factor (expected)	0.082	0.057	0.082 in CZ4 and 0.057 in CZ5
Rate	13 of 28 (46%)	1 of 34 (3%)	14 of 62 (23%)

- **Interpretations:**
  - Looking at the R-values, all of the observations in CZ4 met or exceeded the prescriptive code requirement, but not quite half in CZ5 did, indicating there may be an issue with the amount of insulation in CZ5.
  - In over two-thirds of the above-grade wall observations, the insulation installation quality was rated as Grade II or Grade III. Walls with U-factors above 0.082 in CZ4 had the required

insulation but had insulation installation quality issues. In CZ5, the issue appears to be a mix of not enough insulation installed and insulation installation quality issues.

3.1.1.5 Ceilings

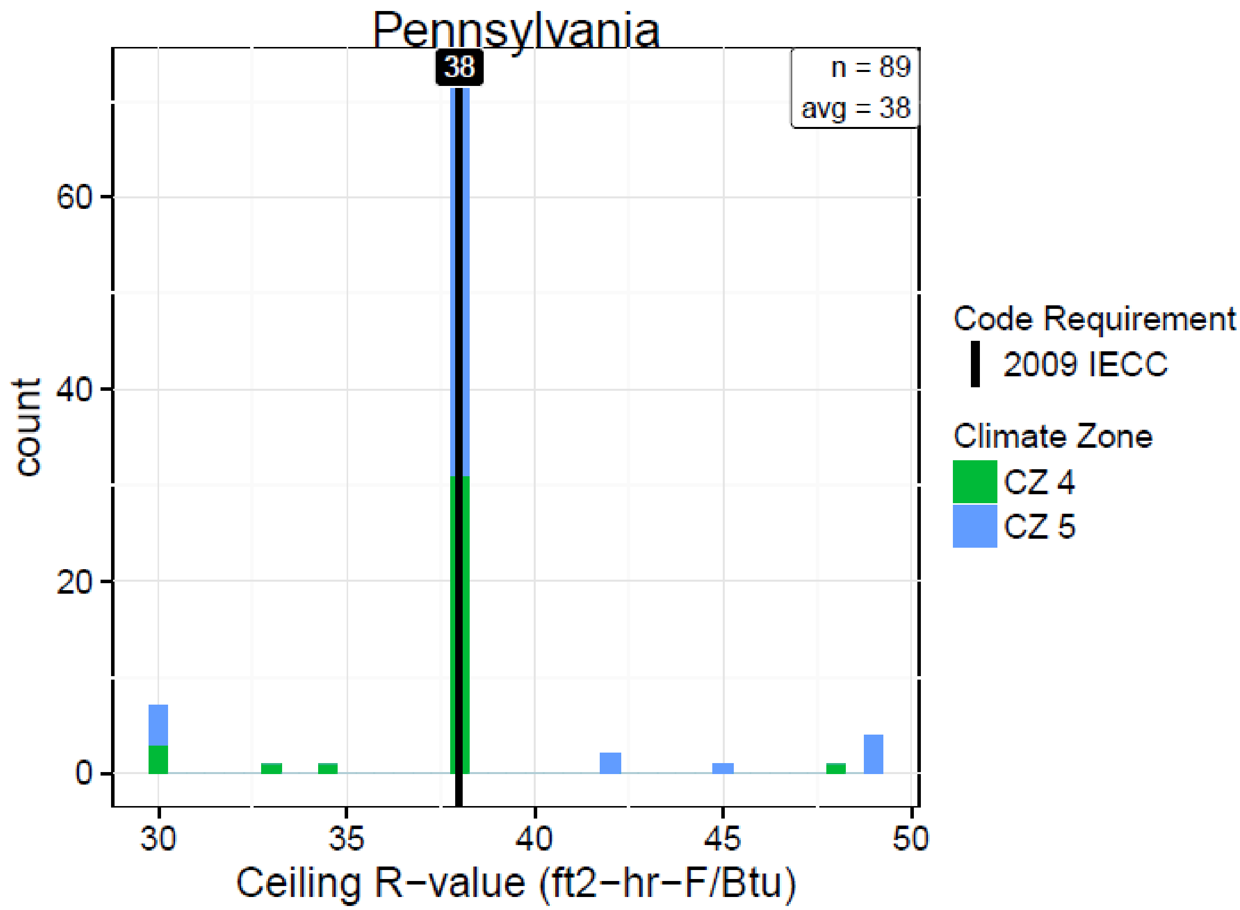

Figure 3.8. Ceiling R-Value

Table 3.5. Ceiling R-Value

Climate Zone	CZ4	CZ5	Statewide
Number	37	52	89
Range	R-30 to R-48	R-30 to R-49	R-30 to R-49
Average	R-37.4	R-38.5	R-38.0
Requirement	R-38	R-38	R-38
Compliance Rate	32 of 37 (86%)	48 of 52 (92%)	80 of 89 (90%)

- **Interpretations:**
  - The vast majority of observations met the code requirement exactly.

– The cause of the instances of R-30 in the field is unclear. R-30 is allowed as an alternative to 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.

– Ceiling insulation does not appear to be an issue; however, nearly half of the observations of ceiling insulation were Grade II, so insulation installation quality may be an area to be pursued in training and education efforts.

3.1.1.6 Lighting

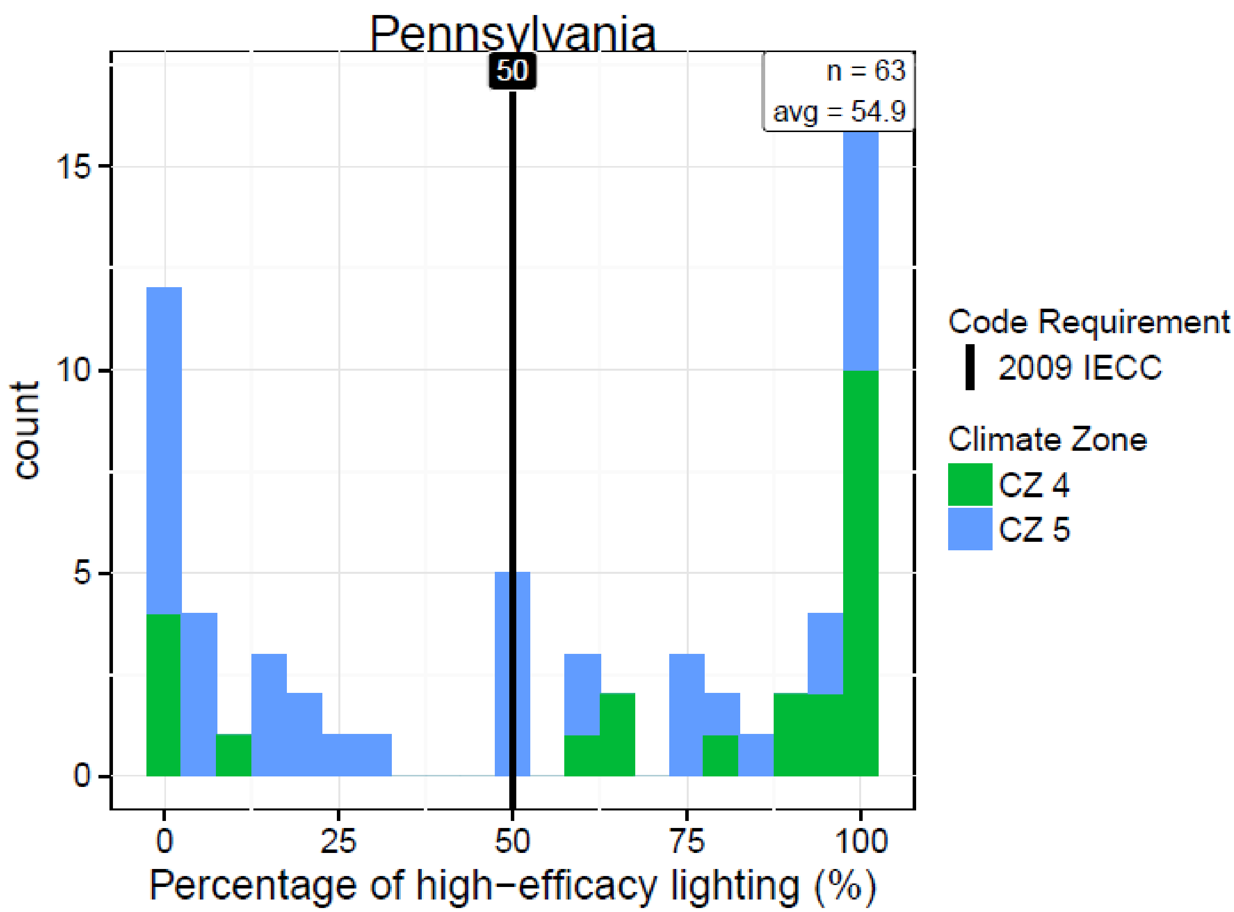

Figure 3.9. High-efficacy Lighting Percentage

Table 3.6. High-efficacy Lighting Percentage

Climate Zone	CZ4	CZ5	Statewide
Number	23	40	63
Range	0 to 100	0 to 100	0 to 100
Average	71.6	45.3	54.9
Requirement	50	50	50
Compliance Rate	18 of 23 (78%)	21 of 40 (53%)	39 or 63 (62%)

- **Interpretations:**
  - A little more than half of the field observations were observed to meet the requirement; a much lower number than expected.
  - Although most of the observations were at 0% and 100%, there was a wide range of non-compliant observations.
  - This should be considered an area for increased attention in future training and enforcement.

3.1.1.7 Foundation Assemblies

There were two predominant foundation types observed in Pennsylvania, heated basements and floors over unheated basements. Two graphs are shown for each climate zone for foundations, 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.

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

Basement Wall Insulation (Conditioned Basements)

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.

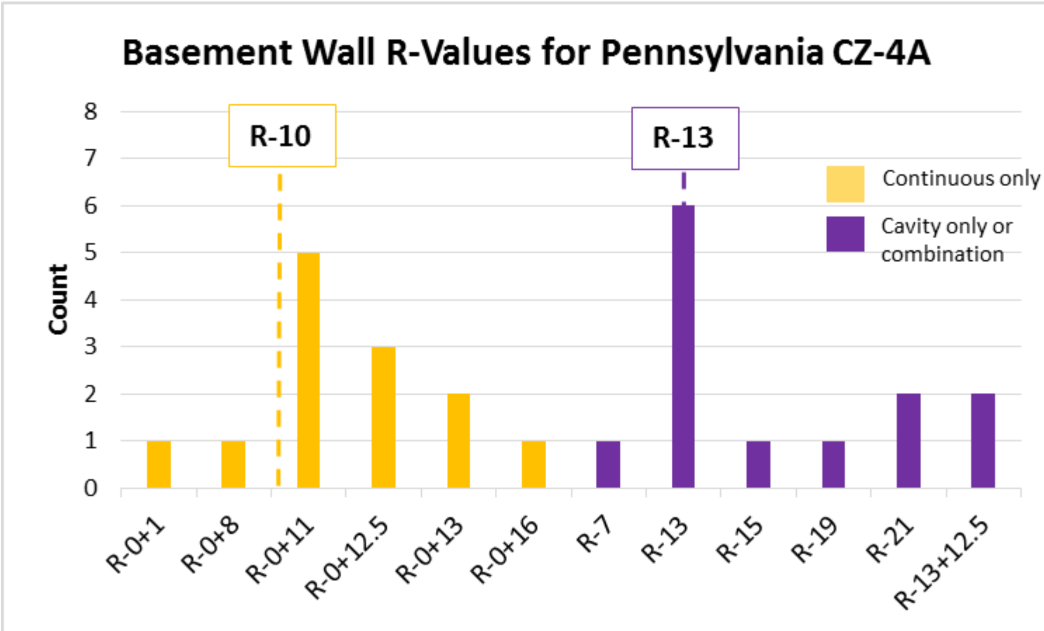

Figure 3.10. Basement Wall R-Values for Pennsylvania CZ4A

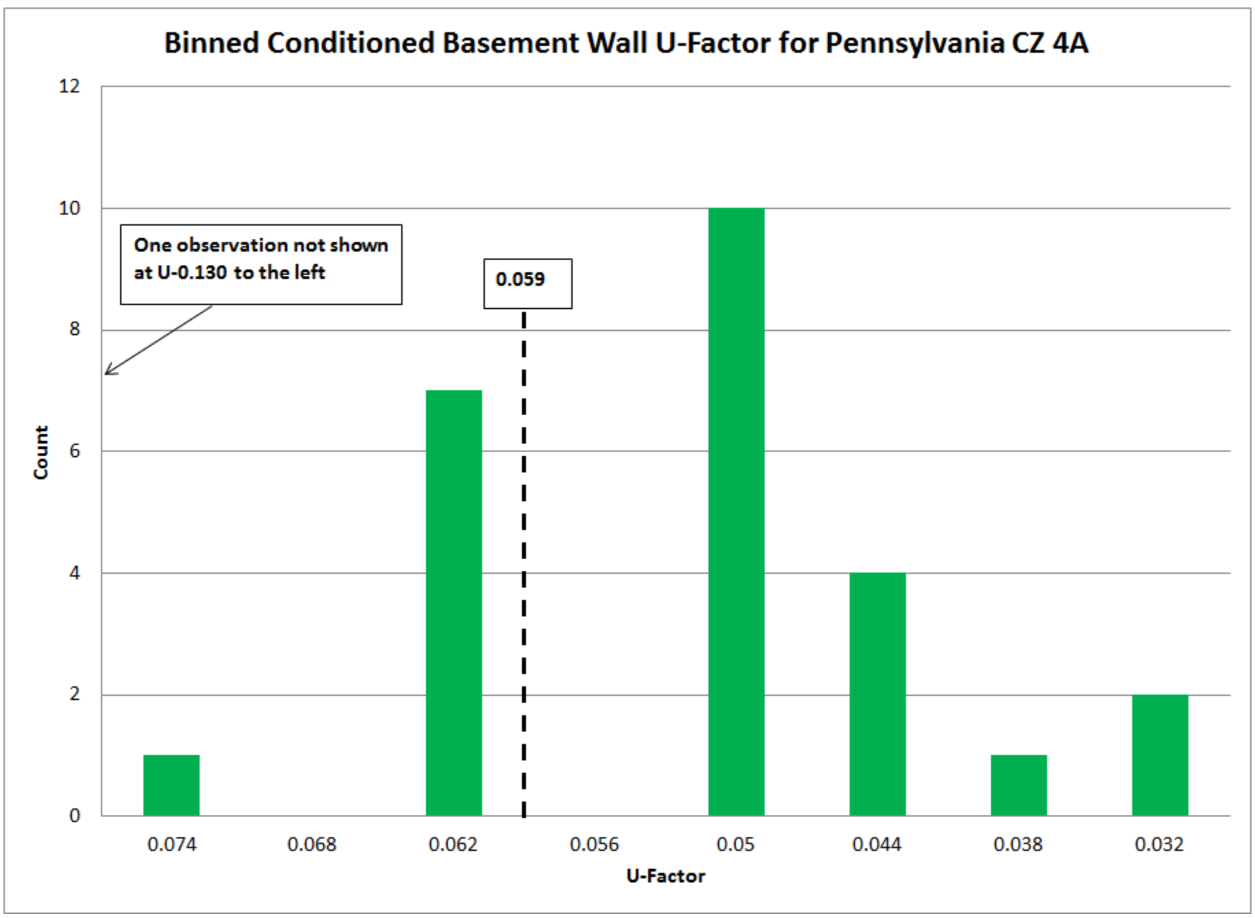

Figure 3.11. Basement Wall Assembly Performance, including Wall Insulation Installation Quality for Pennsylvania CZ4A

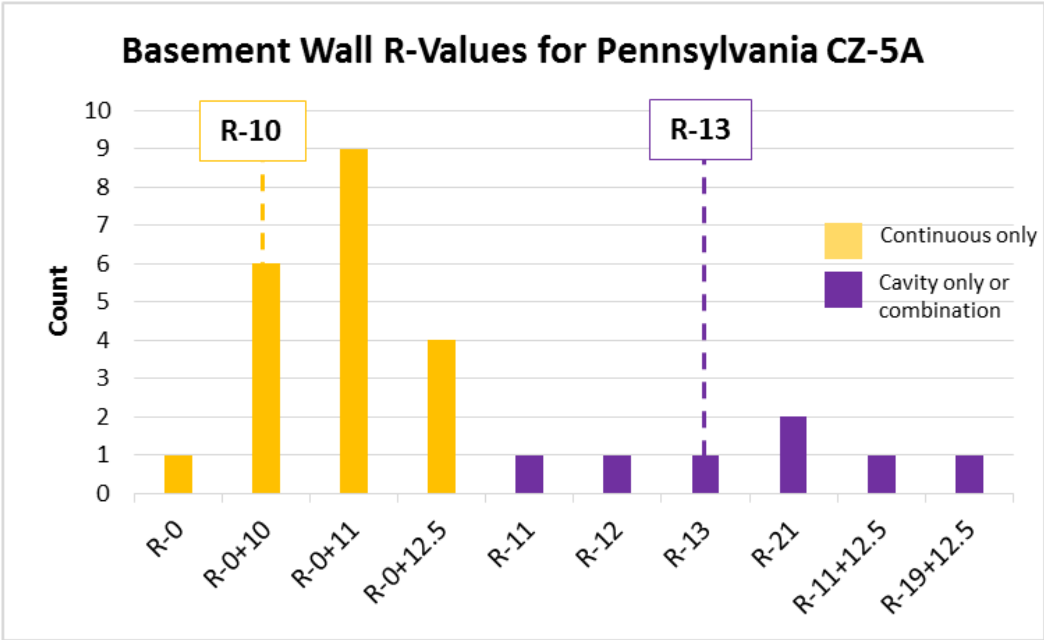

Figure 3.12. Basement Wall R-Values for Pennsylvania CZ5A

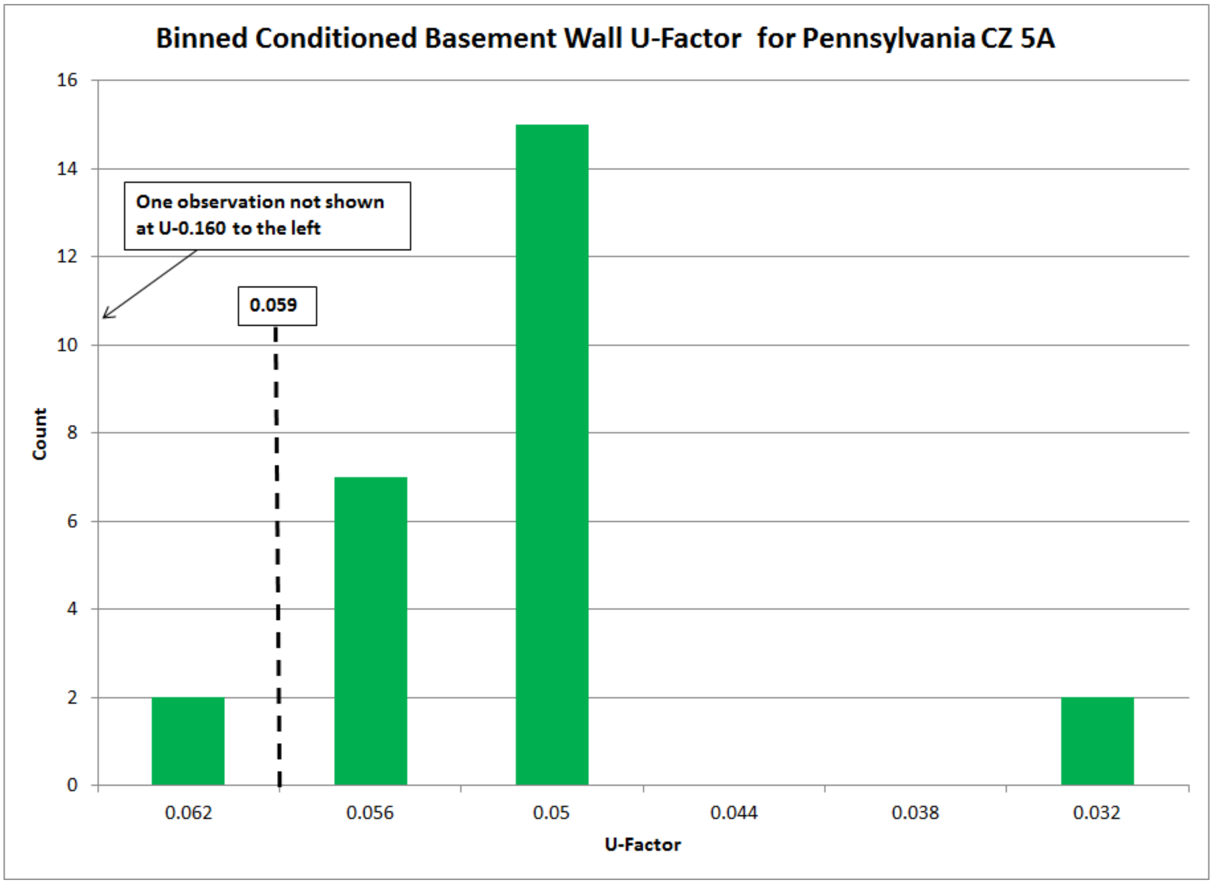

Figure 3.13. Basement Wall Assembly Performance, including Wall Insulation Installation Quality for Pennsylvania CZ5A

Table 3.7. Basement Walls

Climate Zone	CZ4	CZ5	Statewide
Number	26	27	53
Range	0.130 to 0.032	0.163 to 0.029	0.163 to 0.029
Average	0.054	0.054	0.054
Assembly U-Factor (expected)	0.059	0.059	0.059
Rate	19 of 26 (73%)	23 of 27 (85%)*	42 of 53 (79%)

*One observation in the U-0.062 bin is compliant and the other is not.

- **Interpretations:**
  - Comparison of the U-factor and R-value graphs for CZ4 indicates that insulation installation quality may be an issue for basement walls in CZ4.
  - Comparison of the U-factor and R-value charts for CZ5 indicates that insulation installation quality is not an issue for basement walls in CZ5; the issue is the amount of insulation.

Insulation in Floors over Unconditioned Spaces

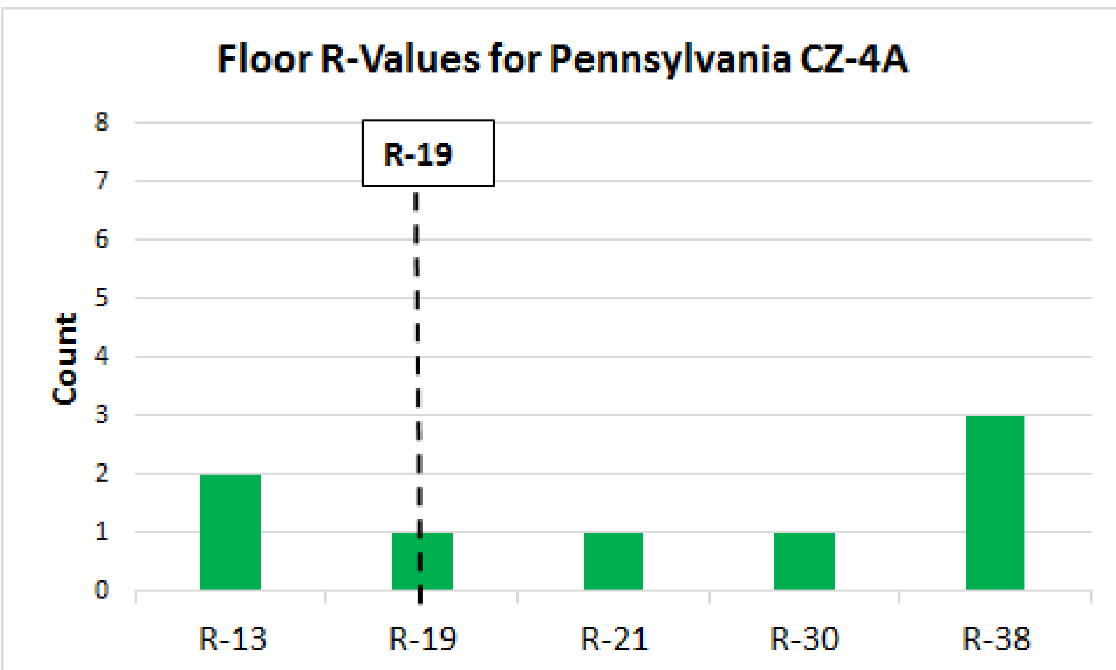

Figure 3.14. Floor R-Values for Pennsylvania CZ4A

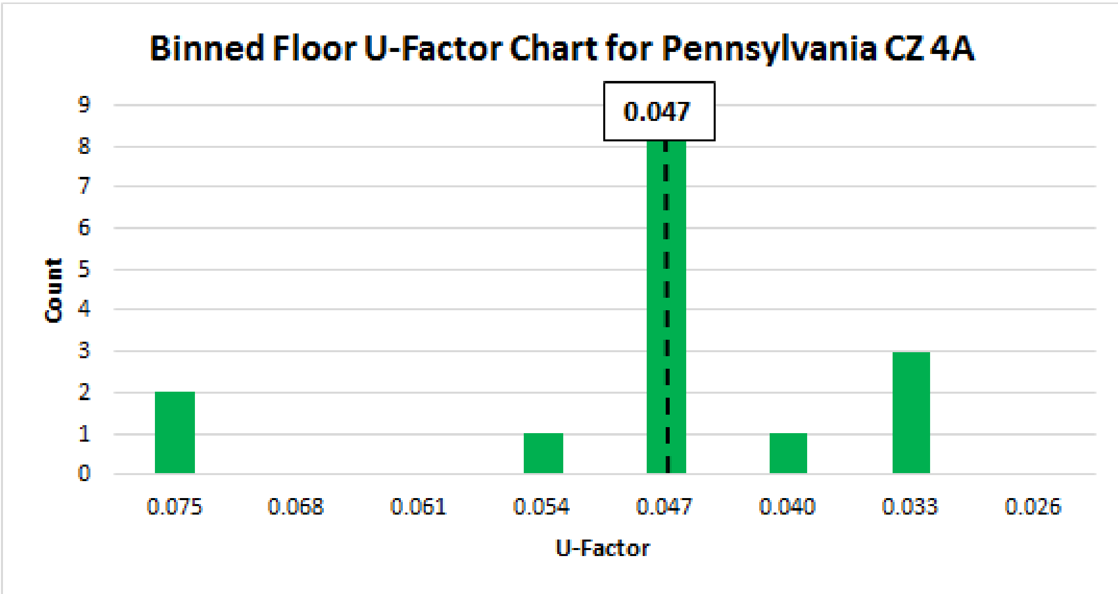

Figure 3.15. Floor Assembly Performance, including Insulation Installation Quality for Pennsylvania CZ4A

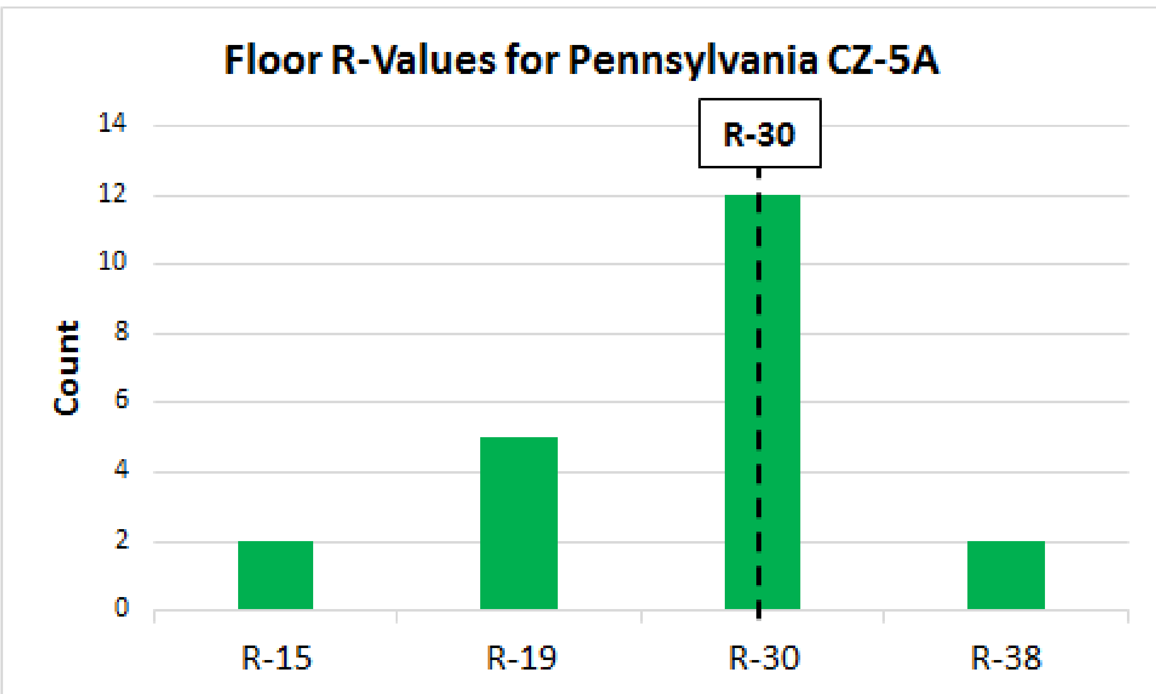

Figure 3.16. Floor R-Values for Pennsylvania CZ5A

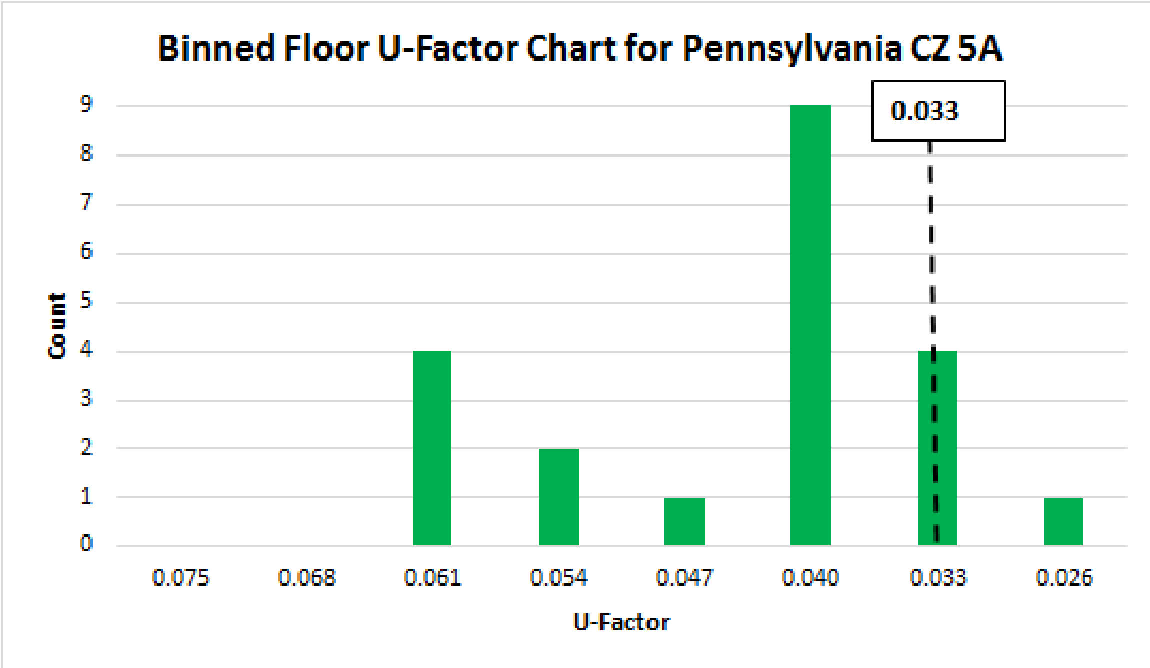

Figure 3.17. Floor Assembly Performance, including Insulation Installation Quality for Pennsylvania CZ5A

Table 3.8. Floors

Climate Zone	CZ4	CZ5	Statewide
Number	8	21	29
Range	0.073 to 0.031	0.060 to 0.027	0.073 to 0.027
Average	0.047	0.042	0.044
Assembly U-Factor (expected)	0.047	0.033	0.047 for CZ4 and 0.033 for CZ5
Rate	5 of 8 (63%)	4 of 21 (19%)	9 of 29 (31%)

- **Interpretations:**
  - Comparison of the U-factor and R-value charts for CZ4 indicates that insulation installation quality is not an issue for floors in CZ4; the issue appears to be the amount of insulation.
  - Comparison of the U-factor and R-value charts for CZ5 indicates that insulation installation quality, as well as insulation levels, appear to be an issue.

3.1.1.8 Duct Tightness

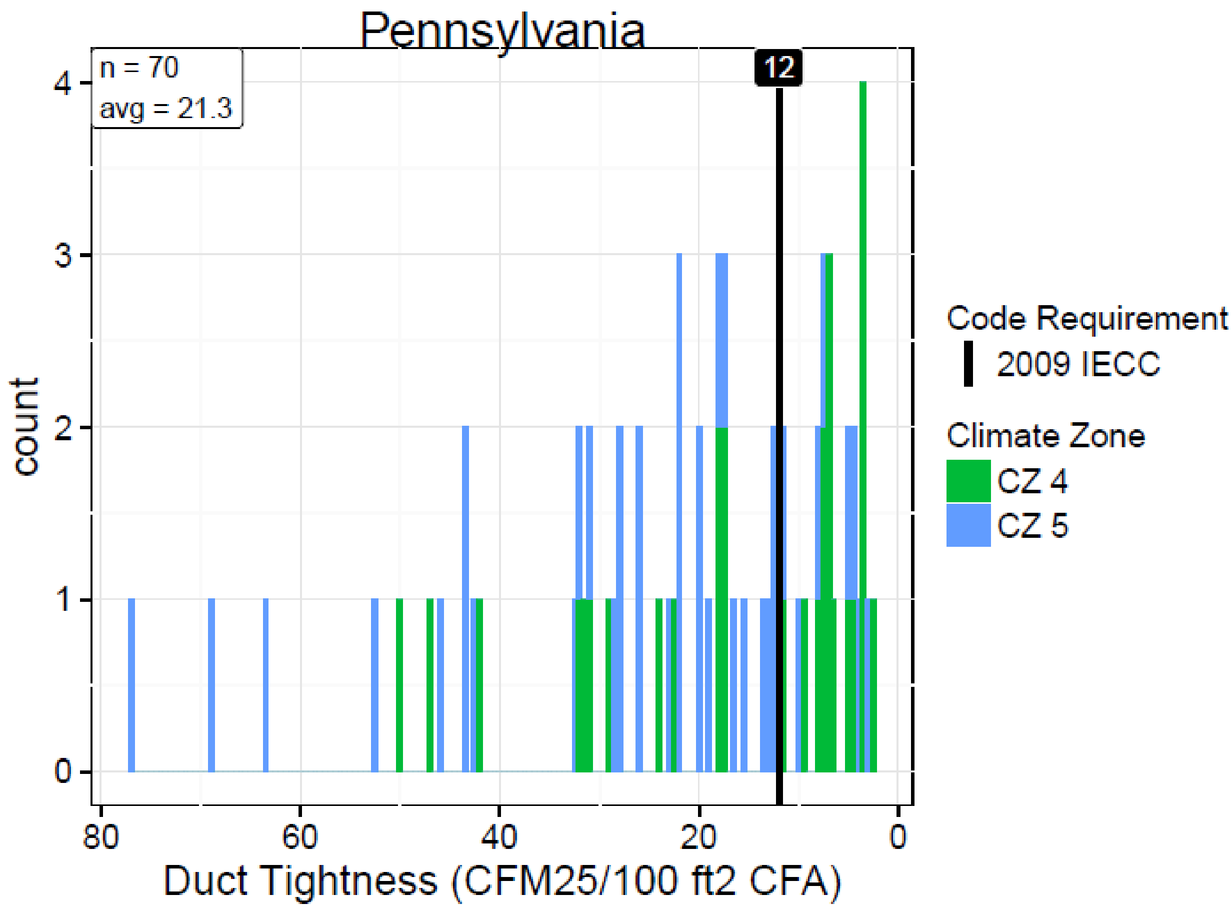

Figure 3.18. Duct Tightness (CFM25/100ft2 CFA)

Table 3.9. Duct Tightness (CFM25/100ft2 CFA)

Climate Zone	CZ4	CZ5	Statewide
Number	30	40	70
Range	2.4 to 50	2.8 to 77.1	2.4 to 77.1
Average	13.8	21.8	21.3
Requirement	12	12	12
Compliance Rate	17 of 30 (57%)	9 of 40 (23%)	26 of 70 (37%)

- **Interpretations:**
  - The average total duct leakage is 18.0 CFM 25/100 ft2 for the 52 systems with ducts in unconditioned space, and 31.0 CFM 25/100 ft2 for the 18 systems located entirely in conditioned space.
  - The majority of observations do not meet the 2009 IECC requirement for duct leakage.
  - Reductions in duct leakage represent a significant area for improvement and should be given increased attention in future training and enforcement.

The project team noted that nearly three-quarters of the HVAC systems tested had some portion of the system located outside of conditioned space. Thus, it would be expected that nearly three-quarters of homes in Pennsylvania require a duct leakage test to be performed. The project team also added that the difference in duct leakage between systems in unconditioned space versus conditioned space probably indicates that code officials, builders, and HVAC contractors are interpreting the exception for duct leakage testing (testing is not required when the entire system is located completely within conditioned space) as an exception to the mandatory sealing requirement, which applies regardless of duct location.

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[1] assessment protocol which has three grades, Grade I being the best quality installation and Grade III being the worst.

Table 3.10 shows the insulation installation quality levels for framed envelope assemblies, as observed in the state. The majority of the observations (131 of 243) were classified as Grades II and III, indicating that there is improvement needed in insulation installation quality.

Table 3.10. Insulation Installation Quality

Assembly	Grade I	Grade II	Grade III	Total Observations
Roof Cavity	47	40	2	**89**
Floor	8	18	2	**28**
Above Grade Wall	20	40	2	**62**
Basement Wall	32	14	0	**46**
Knee Wall	5	13	0	**18**

3.1.2 Additional Data Items

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

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 state field study is contained in Appendix C. The full data set is also available on the DOE Building Energy Codes Program website.[2] *The percentages provided in the section below represent percentages of total observations or the percentage of observations that complied.*

[1] See http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf
[2] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study

3.1.2.1 Average Home

- Size: 2882 ft^2 and 2.13 stories

3.1.2.2 Compliance

- Almost all homes (98%) were permitted under the 2009 IECC. Two percent selected the Pennsylvania Alternative (n=61)
- Seven homes were noted as participating in an above-code program.

3.1.2.3 Envelope

- **Profile:**
  - Walls: All were wood-framed walls with a mix of nominal 2x4" (56%) and 2x6" (44%) studs
  - Foundations: Mix of basements (75%)[3] and slab-on-grade (25%)
- **Successes (percentage of observations that complied):**
  - Insulation labeled (96%)
  - IC-rated light fixtures sealed (84%)
  - Utility penetrations sealed (88%)
- **Areas for Improvement:**
  - Attic access openings complied (73%)
  - Knee walls sealed (33%)
  - Envelope areas behind bathroom tubs & showers sealed (57%)
  - Rim joists sealed (56%)

3.1.2.4 Duct & Piping Systems

- **Profile:**
  - Ducts were generally located within conditioned space (percentage of duct system):
    - Supply: 76% (34 homes entirely within conditioned space)
    - Return: 78% (46 homes entirely within conditioned space)
  - About 45% of homes located *supply* ducts entirely within conditioned space
  - About 59% of homes located *return* ducts entirely within conditioned space
  - About 34% of homes had the *entire* system within conditioned space.
  - Pipe Insulation (R-value): 3.8
- **Successes:**
  - Air handlers sealed (96%)
- **Areas for Improvement:**

[3] Almost all basements observed in the study were conditioned (90%).

– Filter boxes sealed (79%)

3.1.2.5 HVAC Equipment

- **Profile:**
  - Heating: Mostly gas furnaces with an average efficiency of 93 AFUE. All but one furnace observed in the study had an efficiency of 92 AFUE or better.
  - Cooling: Mostly central AC with an average efficiency of 13.3 SEER
  - Water Heating: Mix of gas (73%) and electric (27%) storage with an average capacity of 55 gallons and average efficiency rating of EF 0.82
- **Successes:**
  - Programmable thermostats installed (99%)
  - User manuals for mechanical systems provided (96%)

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, the average home in Pennsylvania appears to use *less* energy than would be expected relative to a home built to the current minimum state code requirements.

Analysis of the collected field data indicates an average regulated EUI (dashed line in Figure 3.19) of approximately 40.73 kBtu/ft^2-yr compared to 45.48 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements (black line in Figure 3.19). This suggests the EUI for a “typical” home in the state is about 10% better than code.

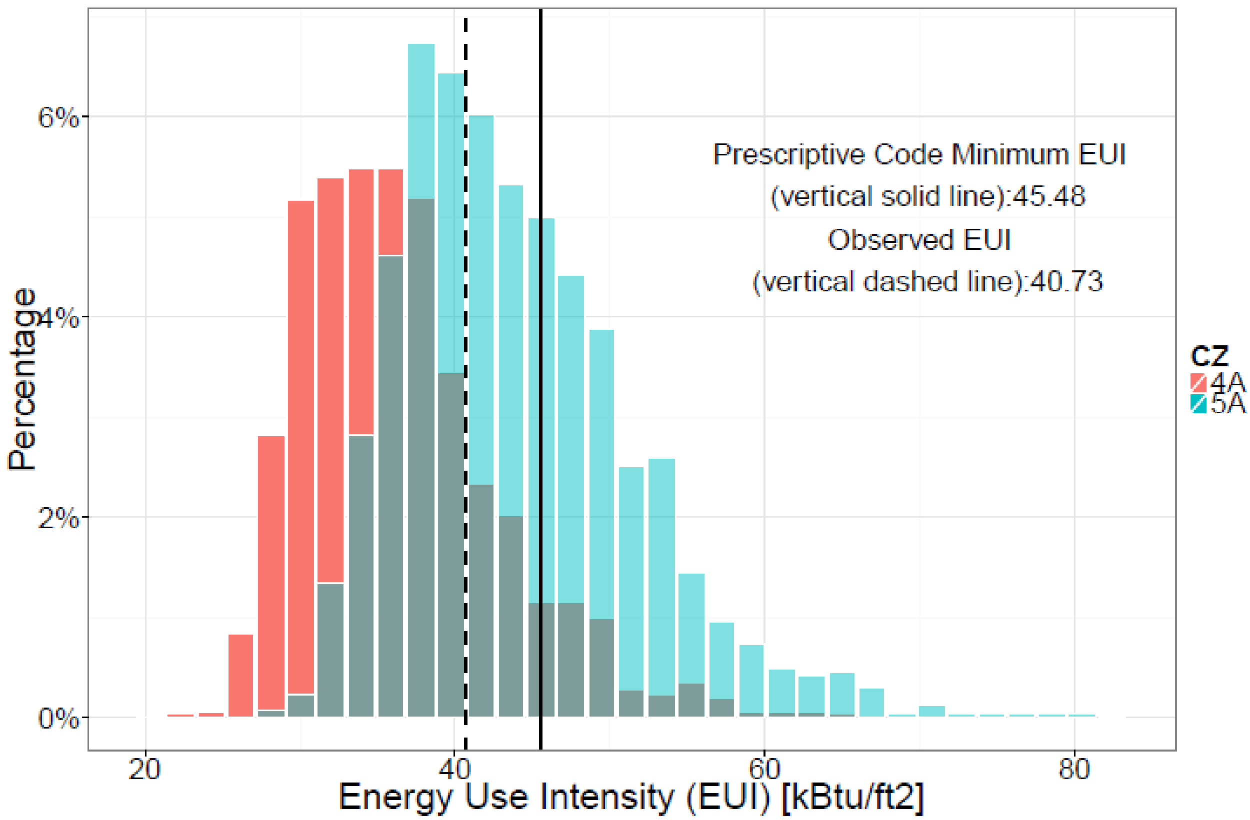

Figure 3.19. Statewide EUI Analysis for Pennsylvania

3.3 Savings Potential

Those key items with the greatest potential[4], shown below followed by the percent that did not meet code, were analyzed further to calculate the associated savings potential, including energy, cost and carbon savings.

- Duct Leakage (58%),
- Exterior Wall Insulation (37%),
- Lighting (38%),
- Foundations
  - Basement Wall Insulation (21%), and
  - Floor Insulation (69%).

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

Estimated savings resulting from the analysis are shown below in order of highest to lowest total energy, cost and carbon savings (Table 3.11). As can be seen, there are significant savings opportunities, with the greatest total savings potential associated with these measures. In addition, Table 3.13 shows the total savings and emissions reductions that will accumulate over 5, 10, and 30 years of construction.

[4] Defined here as those with more than 15% of observations not meeting the prescriptive code requirement

Table 3.11. Statewide Annual Measure-Level Savings for Pennsylvania

Measure	Climate Zone	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Duct Leakage	4A	215	46	5,359	7,040	37,728	594,504	2,761
	5A	206	45	5,233	9,331	48,828	766,056	3,552
	State Total	**210**	**46**	**5,287**	**16,371**	**86,553**	**1,360,493**	**6,363**
Exterior Wall Insulation	4A	16	5	532	7,040	3,745	55,233	264
	5A	159	49	5,449	9,331	50,849	742,797	3,447
	State Total	**98**	**30**	**3,335**	**16,371**	**54,594**	**798,031**	**3,710**
Foundation Insulation*	4A	-31	16	1,482	6,312	6,573	66,149	302
	5A	-61	22	2,016	8,366	11,138	109,462	499
	State Total	**-48**	**20**	**1,788**	**14,677**	**17,711**	**175,610**	**802**
Lighting*	4A	179	-3	312	7,040	2,193	158,333	757
	5A	179	-3	287	9,331	2,676	206,930	1,003
	State Total	**179**	**-3**	**297**	**16,371**	**4,868**	**365,254**	**1,760**
TOTAL		**439**	**93**	**10,707**		**163,726**	**2,699,388**	**12,635**

* 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.

**See Table 3.12 for annual measure-level savings results by foundation type.

Table 3.12. Statewide Annual Measure-Level Savings by Foundation Type for Pennsylvania

Measure	Climate Zone	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Basement Wall Insulation *	4A	-13	14	1,392	4,612	6,419	67,548	309
	5A	-11	17	1,708	6,113	10,444	113,480	520
	State Total	**-12**	**16**	**1,573**	**10,726****	**16,864**	**181,029**	**830**
Floor Insulation *	4A	-18	2	91	1,699	154	-1,400	-7
	5A	-50	5	308	2,252	693	-4,019	-21
	State Total	**-36**	**3**	**215**	**3,952****	**847**	**-5,418**	**-28**
TOTAL		**-48**	**20**	**1,788**	**14,677**	**17,711**	**175,610**	**802**

*For basement wall insulation and floor insulation, note that while total energy savings are positive, electricity savings are negative. This is the result of increased insulation leading to lower natural gas usage in the winter, but higher electricity usage in the summer. Note also that floor insulation total energy cost savings and emissions reductions are negative, even though total energy savings are positive. This is again related to lower gas usage in the winter, but higher electricity use in the summer.
** 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 3.13. Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings for Pennsylvania

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
	5yr	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Leakage	1,298,295	4,760,415	40,247,145	20,407,395	74,827,115	632,629,245	95,445	349,965	2,958,795
Exterior Wall Insulation	818,910	3,002,670	25,386,210	11,970,465	43,891,705	371,084,415	55,650	204,050	1,725,150
Foundation Insulation	265,666	974,110	8,235,655	2,634,154	9,658,563	81,658,761	12,023	44,086	372,723
Lighting	73,020	267,740	2,263,620	5,478,810	20,088,970	169,843,110	26,400	96,800	818,400
TOTAL	**2,455,891**	**9,004,935**	**76,132,630**	**40,490,824**	**148,466,353**	**1,255,215,531**	**189,518**	**694,901**	**5,875,068**

4.0 Conclusions

The Pennsylvania field study provides an enhanced understanding of statewide code implementation, and suggests that significant savings are available through increased compliance. From a statewide perspective, the average home in Pennsylvania uses about 10% less energy than a home exactly meeting the state energy code. However, significant savings potential remains through increased compliance with targeted measures. Potential statewide annual energy savings are 163,726 MMBtu, which equates to $2,699,388 in cost savings, and emission reductions of 12,635 MT CO2e. Over a 30-year period, these impacts grow to 76.1 million MMBtu, $1.26 billion, and over 5.8 million metric tons 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 Pennsylvania

	Annual Savings		
Key Measure	**Energy** (MMBtu)	**Cost** ($)	**Carbon** (MT CO2e)
Duct Leakage	86,553	1,360,493	6,363
Exterior Wall Insulation	54,594	798,031	3,710
Foundation Insulation	17,711	175,611	802
Lighting	4,868	365,254	1,760
Total	**163,726 MMBtu**	**$2,699,388**	**12,635 MT CO2e**

5.0 References

Census Bureau. 2016. Censtats Building Permits Database. http://censtats.census.gov/

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

DOE Building Energy Codes Program's residential field study website is available at https://www.energycodes.gov/compliance/residential-energy-code-field-study (accessed August 8, 2016).

DOE/PNNL 2016a. "Protocol for Measuring Residential Energy Code Compliance." Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study

DOE/PNNL 2016b. "Residential Energy Code Field Study Data Analysis: Technical Support Document." Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study

EnergyPlus. https://energyplus.net/.

The Pennsylvania residential field study website is available at http://pennenergycodes.com/ (accessed August 8, 2016).

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

Appendix A

Stakeholder Participation

Appendix A

Stakeholder Participation

A.1 Stakeholder Participation

Table A.1. Stakeholder Participation in Project Kickoff Meeting

Stakeholder	Description
Pennsylvania Builders Association (PBA) and their network of local associations	Key stakeholder in all residential energy code matters as its members are directly regulated by energy codes. Its members also provide access to individual homes under construction.
Pennsylvania Association of Building Code Officials (PABCO)	Organization of code officials that focuses largely on legislative and policy issues in PA.
Pennsylvania Building Code Officials Conference (PENNBOC)	This organization is more focused on training and education of code officials and consists of several ICC Chapters.
Pennsylvania Construction Codes Academy (PCCA)	This organization is funded by the state and is charged with code official training.
Pennsylvania Housing Research Center (PHRC)	This organization, based at Penn State, receives funding from the state for contractor education and other applied projects.
American Institute of Architects (AIA) – Pennsylvania Chapter	State chapter of AIA.
Air Conditioning Contractors of America (ACCA)	Organization of HVAC contractors.
Independent HERS Rating companies	This is not a single organization but numerous independent companies that provide HERS Ratings for builders.
Pennsylvania Public Utility Commission (PUC)	Oversees the implementation of Pennsylvania Act 129 Energy Efficiency & Conservation Programs offered by Pennsylvania EDCs.
Electric Distribution Companies (EDCs)	Implement a variety of Energy Efficiency & Conservation programs, including New Homes programs that are closely related to energy codes.
Pennsylvania Department of Environmental Protection (DEP)	The Office of Pollution Prevention and Energy Assistance serves as the state energy office.
Pennsylvania Energy Code Compliance Collaborative	This informal group is moderated by NEEP and meets quarterly to discuss and promote energy code compliance activities in Pennsylvania.
NEEP	Leads the Pennsylvania Energy Code Compliance Collaborative.
Pennsylvania Department of Labor & Industry (DLI)	The department responsible for regulations pertaining to the adoption and enforcement of building codes.
Pennsylvania Department of Community & Economic Development (DCED)	All building code training funds distributed to PCCA and the PHRC flow through DCED.

Appendix B

State Sampling Plan

Appendix B

State Sampling Plan

B.1 State Sampling Plan

Table B.1. State Sampling Plan

PLACE, COUNTY	PLACE, COUNTY	SAMPLE	ACTUAL
BENSALEM TOWNSHIP, BUCKS		1	1.5
BUCKINGHAM TOWNSHIP, BUCKS		1	0
	Maxatawny township, Berks	0	1
BUSHKILL TOWNSHIP, NORTHAMPTON		1	0
	Palmer township, Northampton	0	1
CENTER TOWNSHIP, SNYDER		1	0
DOUGLASS TOWNSHIP, BERKS		1	0
	Lower Heidelberg township, Berks	0	1
DOVER TOWNSHIP, YORK		2	1.5
EAST BRANDYWINE TOWNSHIP, CHESTER		2	2
	Weisenberg township, Lehigh	0	1
EAST BUFFALO TOWNSHIP, UNION		1	0
	Upper Nazareth township, Northampton	0	1
EAST DONEGAL TOWNSHIP, LANCASTER		1	2
EAST HEMPFIELD TOWNSHIP, LANCASTER		1	2
EAST PIKELAND TOWNSHIP, CHESTER		1	0
	Honey Brook township, Chester	0	1
	Sadsbury township, Chester	0	1
HAMPDEN TOWNSHIP, CUMBERLAND		1	3
KENNETT TOWNSHIP, CHESTER		1	1.5
LOWER MACUNGIE TOWNSHIP, LEHIGH		1	3
LOWER MAKEFIELD TOWNSHIP, BUCKS		2	2
LOWER PAXTON TOWNSHIP, DAUPHIN		2	2
MARPLE TOWNSHIP, DELAWARE		1	0
	Radnor township, Delaware	0	1
MIDDLESEX TOWNSHIP, CUMBERLAND		1	0
	Swatara township, Cumberland	0	1.5
MOUNT JOY BOROUGH, LANCASTER		1	2
NEW LONDON TOWNSHIP, CHESTER		1	0
	Sadsbury township, Chester	0	1
	Ontelaunee township, Berks	0	0.5
NORTH MIDDLETON TOWNSHIP, CUMBERLAND		1	2
PEACH BOTTOM TOWNSHIP, YORK		1	1
PERRY COUNTY PART UNINCORPORATED		1	0
AREA, PERRY	Peach Bottom township, York	0	1
PHILADELPHIA, PHILADELPHIA		5	4
PHOENIXVILLE BOROUGH, CHESTER		1	2

PLACE, COUNTY	PLACE, COUNTY	SAMPLE	ACTUAL
PINE TOWNSHIP, COLUMBIA		3	0
	Muhlenberg township, Berks	0	3
PINE TOWNSHIP, LYCOMING		2	0
	Loyalsock township, Lycoming	0	1
	Palmer township, Northampton	0	1
PLUMSTEAD TOWNSHIP, BUCKS		1	2
POTTSTOWN BOROUGH, MONTGOMERY		2	1.5
	Northampton township, Northampton	0	1
RAPHO TOWNSHIP, LANCASTER		1	1
RICE TOWNSHIP, LUZERNE		1	0
	North Whitehall township, Lehigh	0	2
ROBESON TOWNSHIP, BERKS		1	0
	New Hanover township, Montgomery	0	1
SILVER SPRING TOWNSHIP, CUMBERLAND		4	2
	Mainheim township, Lancaster	0	3.5
SOUTH MIDDLETON TOWNSHIP, CUMBERLAND		1	1
SOUTH WHITEHALL TOWNSHIP, LEHIGH		1	1
TOWAMENCIN TOWNSHIP, MONTGOMERY		1	0
	Lower Salford township, Montgomery	0	1
UPPER ALLEN TOWNSHIP, CUMBERLAND		2	4
UPPER MACUNGIE TOWNSHIP, LEHIGH		1	4
UPPER SAUCON TOWNSHIP, LEHIGH		1	1
WARRINGTON TOWNSHIP, BUCKS		1	1.5
WARWICK TOWNSHIP, LANCASTER		1	1
WEST GOSHEN TOWNSHIP, CHESTER		3	0
	London Grove township, Chester	0	2
	Willistown township, Chester	0	1
WEST HANOVER TOWNSHIP, DAUPHIN		1	1
WORCESTER TOWNSHIP, MONTGOMERY		1	1
YORK, YORK		1	2
TOTAL		63	82

B.2 Substitutions

In the Pennsylvania study, the following substitutions were made:

- Municipality substitutions and combinations were required to collect the 63 sets of the eight key observation items. Overall, the PSD team visited 51 municipalities. The PSD team was not able to collect data in 17 of the original 45 sample plan municipalities.[1] Substitutions were selected based on

[1] The original sample plan provided to PA directed the Project Team to visit a number of municipalities that did not have adequate numbers of homes under construction. The sample plan development methodology assumed that there were unique municipality names in each state, however, PA is unique in that multiple municipalities have the same name within the state. For example, in the data set used to develop the sample plan, there are 18 municipalities called “Washington Township”. These municipalities are in different counties, but the sample plan was focused solely on the municipality name and therefore some locations were included inadvertently.

comparable geographic location, population, population density, racial makeup, median household income and three-year permit average per the Census.

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 Pennsylvania 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=148): 2882 ft^2
- Number of Stories (n=146): 2.13

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

Conditioned Floor Area (ft^2)	< 1000	1000 to 1999	2000 to 2999	3000 to 3999	4000+
Percentage	1%	28%	36%	17%	18%

Table C.2. Number of Stories

No. of Stories	1	2	3	4+
Percentage	10%	68%	23%	0%

C.1.1.2 Wall Profile

- Framing Type (n=162):
  - *All* were framed construction (100%)
- Framing Material (n=148):
  - Wood (100%)

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

- Steel (0%)

- Framing Depth (n=132):
  - 4” (56%)
  - 6” (44%)

C.1.1.3 Foundation Profile

- Foundation Type (n=171):
  - Basement (79%)
  - Slab on Grade (21%)
  - Crawlspace (0%)
- Basement Type (n=100):
  - Conditioned (77%)
  - Unconditioned (23%)

C.1.1.4 Other

- *None* had a pool or spa (n=130)
- *None* had a sunroom (n=134)

C.1.1.5 Builder Profile

- Average number of Homes Built Annually (n=36): 96 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	14%	33%	6%	47%

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=61):

Table C.4, Energy Code Used

Energy Code	2009 IECC	Pennsylvania Alternative
Percentage	98%	2%

- Was the home participating in an above-code program (n=30)?
  - Yes (23%)
  - No (77%)

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=49)?
  - Yes (96%)
  - No (4%)

C.1.3.2 Ceilings

- Did the attic hatch/door exhibit the correct insulation value (n=61)?
  - Yes (69%)
  - No (31%)

C.1.3.3 Air Sealing[1]

- Thermal envelope sealed (n=27) (74%)
- Openings around windows and doors sealed (n=40) (95%)
- Utility penetrations sealed (n=52) (88%)
- Dropped ceilings sealed (n=33) (97%)
- Knee walls sealed (n=21) (67%)
- Garage walls and ceilings sealed (n=55) (82%)
- Envelope behind tubs and showers sealed (n=28) (57%)
- Common walls sealed (n=17) (94%)
- Attic access openings sealed (n=67) (73%)
- Rim joists sealed (n=56) (56%)
- Other sources of infiltration sealed (n=16) (94%)
- IC-rated light fixtures sealed (n=31) (84%)

[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 (percentage):
  - *Supply* (n=96): 76% (34 homes with systems located entirely within conditioned space)
  - *Return* (n=95): 78% (46 homes with systems located entirely within conditioned space)
- Duct Insulation (R-value):
  - *Supply* (n=26): 5.9
  - *Return* (n=25): 5.5
- Air ducts sealed (n=53) (85%)
- Air handlers sealed (n=58) (93%)
- Filter boxes sealed (n=85) (79%)

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=116):
  - Gas (95%)
  - Electricity (5%)
- System Type (n=116):
  - Furnace (95%)
  - Heat Pump (5%)
- System Capacity (n=46):
  - Furnace: 70,065 Btu
  - Heat Pump: NA (no capacities noted in data)
- System Efficiency (n=60):
  - Furnace: 93 AFUE (*all but one* observed furnaces had an efficiency of 92 AFUE or better)
  - Heat Pump: 9 HSPF

C.1.5.2 Cooling

- System Type (n=82):
  - Central AC (98%)

- Heat Pump (2%)
- System Capacity (n=23):
  - 33,000 (Btu/hr)
- System Efficiency (n=30):
  - 13.3 SEER (observations ranged from 13 to16 SEER)

C.1.5.3 Water Heating

- Fuel Source (n=107):
  - Gas (73%)
  - Electric (27%)
- System Type (n=71):
  - Storage (96%)
  - Tankless (4%)
- System Capacity (n=62):
  - 55 gallons (observations ranged from 50 to 80 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	0%	76%	13%	2%	10%	0%

- System Efficiency (n=19):
  - EF 0.82 (range from EF 0.63 to EF 0.94)

C.1.5.4 Ventilation

- System Type (n=7):
  - Exhaust Only (71%)
  - Standalone ERV/HRV (29%)
- Exhaust Fan Type (n=5):
  - Dedicated Exhaust (0%)
  - Bathroom Fan (100%)

C.1.5.5 Other

- Mechanical manuals provided (n=70) (96%)
- A programmable thermostat installed (n=67) (99%)

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