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Pennsylvania Residential Energy Code Field Study: Final Report

September 2022

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U.S. DEPARTMENT OF ENERGY

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

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

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

Background

The baseline field study (Phase I) was initiated in 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 Phase I data led to a better understanding of the energy features typically present in Pennsylvania homes, and indicated over $3.1 million in potential annual savings to homeowners in the state that could result from increased code compliance (Table ES.1).

Starting in April 2015 and continuing through April 2017, members of the Pennsylvania field study team conducted targeted education and training activities (Phase II). Those activities included circuit rider assistance[1], in-person trainings, an energy code hotline, and online videos. More information on the specific education and training activities employed in the state is included in Section 2.5. Following the baseline study and the education and training phases, the research team conducted the post-study (Phase III), visiting an additional 160 homes across the state between July 2017 and March 2018. The results of this effort are presented Table ES.1 and discussed further in Section 3.0.

Methodology

The project team was led by 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[2]. As part of both the pre- and post-studies, the project team implemented customized sampling plans representative of new construction within the state, which were originally developed by Pacific Northwest National Laboratory (PNNL) and then vetted with stakeholders.

[1] A *circuit rider* is an individual with subject matter expertise who mobilizes to serve multiple jurisdictions across a given geographic area (e.g., providing insight, expertise and training on compliance best practices).
[2] See Section 2.1.

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

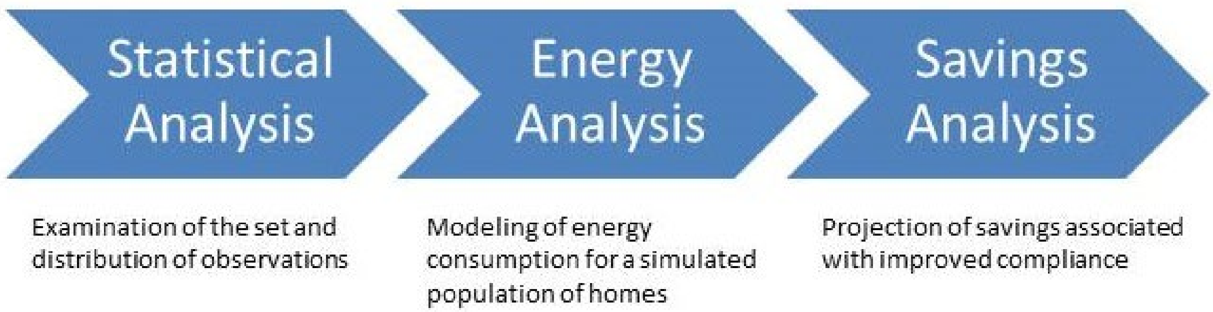

Figure ES.1. Stages of Analysis Applied in the Study

Success for the study is characterized by the following between Phase I and Phase III: 1) a measurable decrease in estimated statewide energy use [a change in energy use intensity (EUI) of at least 2.35 kBtu/ft^2 for Pennsylvania] and 2) a reduction in measure-level savings potential. To estimate average statewide energy consumption, field data was analyzed to calculate average statewide energy use as characterized by EUI. Field observations from Phase I and Phase III were analyzed independently and compared to a scenario based on the state energy code's minimum prescriptive requirements. The Phase III results were then compared to the Phase I results to determine whether a measurable change could be detected.

Results

As shown in Table ES.1, the Phase I analysis indicated homes used about 10.4 percent less energy than would be expected relative to homes built to the minimum prescriptive requirements of the current state code. The average energy use increased between Phases I and III rather than decreased. Despite this increase, modeled Phase III homes still outperformed the prescriptive EUI of the state code.

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

Prescriptive EUI[1]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
45.48	40.73	-10.4%	43.70	-3.9%	-7.3%

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

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

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

Table ES.2. Estimated Annual Statewide Cost Savings Potential

Measure	Total Energy Cost Savings Potential ($)		$ Change	% Change
	Phase I	Phase III	Phase III vs. I	Phase III vs. I
Duct Tightness	1,360,493	1,160,783	-199,711	-15%
Exterior Wall Insulation	798,031	903,673	+105,642	+13%
Ceiling Insulation	499,392	893,386	+393,994	+79%
Lighting	365,254	41,178	-324,077	-89%
Foundation Insulation	175,676	14,477	-161,199	-92%
TOTAL	**$3,198,847**	**$3,013,496**	**-$185,350**	**-5.8%**

Overall, there was a reduction in savings potential between Phase I and Phase III. This is an improvement of nearly 6 percent and over $185,000 in annual cost savings achieved by Phase II targeted education and training activities. Significant improvements occurred in lighting and foundation insulation, and duct tightness is trending in the right direction.

Note that while the EUI in Phase III was about 7.3% "worse" than in Phase I, the measure level savings in Phase III are about 5.8% "better" than in Phase I. The reason that this can happen is that EUI and measure level savings show two distinctly different facets of the housing stock in Pennsylvania.

- EUI captures the energy impacts of the population of observations, including observations that fail to meet code, observations that meet code, and observations that exceed the performance of the code.
- The measure level savings focuses solely on observations that fail to meet code.

Thus, if Phase III had fewer observations that exceeded the code requirement (or the magnitudes of those observations were less compared to code), the EUI in Phase III would be worse than that in Phase I. And if the number and magnitude of observations that failed to meet code improved in Phase III, the measure level savings in Phase III would be better than in Phase I. The two metrics are independent.

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

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

Acknowledgments

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

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

- 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.

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- 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
SHGC	solar heat gain coefficient

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1.0 Introduction

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

The baseline field study (Phase I) was initiated in October 2014 and continued through July 2015. During this period, research teams visited 171 homes across the state during various stages of construction, resulting in a substantial data set based on observations made directly in the field. Analysis of the Phase I data led to a better understanding of the energy features typically present in Pennsylvania homes, and indicated nearly $3.2 million[1] in potential annual savings to homeowners in the state that could result from increased code compliance.

Starting in April 2015 and continuing through April 2017, members of the Pennsylvania field study team conducted targeted education and training activities (Phase II). Those activities included circuit rider assistance[2], in-person trainings, an energy code hotline, and online videos. More information on the specific education and training activities employed in the state is included in Section 2.5.

Following the baseline study and the education and training phases, the research team conducted the post-study (Phase III), visiting an additional 160 homes across the state between April 2015 and April 2017. The results of this effort are presented in Section 3.0. At the time of the study, the state had the 2009 International Energy Conservation Code (IECC), 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)[3] with the goal of determining whether an investment in education, training, and outreach programs can produce a significant, measurable change in single-family residential building code energy use. Participating states:

[1] The original Phase I savings potential estimate was $2.7 million. Following the release of the Phase I report, it was determined that some adjustments were needed to reflect more accurate results related to ceilings (the original savings potential estimates included Ceiling R-values rather than Ceiling U-factors). The revised savings potential amount is $3.2 million.

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

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

- Conducted a **baseline field study** to determine installed energy values of code-required items, identify issues, and calculate savings opportunities [Phase I];
- Implemented **education and training** activities designed to increase code compliance [Phase II]; and
- Conducted a **second field study** to re-measure the post-training values using the same methodology as the baseline study [Phase III].

Energy codes for residential buildings have advanced significantly in recent years, with today's model codes approximately 30% more efficient than codes adopted by the majority of U.S. states.[4,5] Hence, the importance of ensuring code-intended energy savings, so that homeowners realize the benefits of improved codes—something which happens only through high levels of compliance. More information on the original FOA and overall goals of the study is available on the DOE Building Energy Codes Program website.[6]

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.

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

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

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

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

2.0 Methodology

2.1 Overview

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

Highlights of the methodology:

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

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

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

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

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

Success for the study is characterized by the following between Phase I and Phase III: 1) a measurable decrease in estimated statewide energy use [a change in energy use intensity (EUI) of at least 2.3 kBtu/ft^2 for Pennsylvania] and 2) a reduction in measure-level savings potential.

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 DOE data collection and analysis methodology is published separately from this report (DOE 2018) and is available on the DOE Building Energy Codes Program website.[3]

2.2 State Study

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

2.2.1 Sampling

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

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

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).

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

2.2.2.1 Data Collection Form

The field teams relied on a data collection form customized to the mandatory and prescriptive requirements of the state energy code, the 2009 IECC[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 tightness test on every home where such tests could be conducted, using RESNET[7] protocols.

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

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

[5] Pennsylvania Alternative option requirements for Lighting were also included.

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

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

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

2.2.2.2 Data Management and Availability

Once 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 for each Phase is available in spreadsheet format on the DOE Building Energy Codes Program website[8].

2.3 Data Analysis

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

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

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

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

2.3.1 Statistical Analysis

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

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

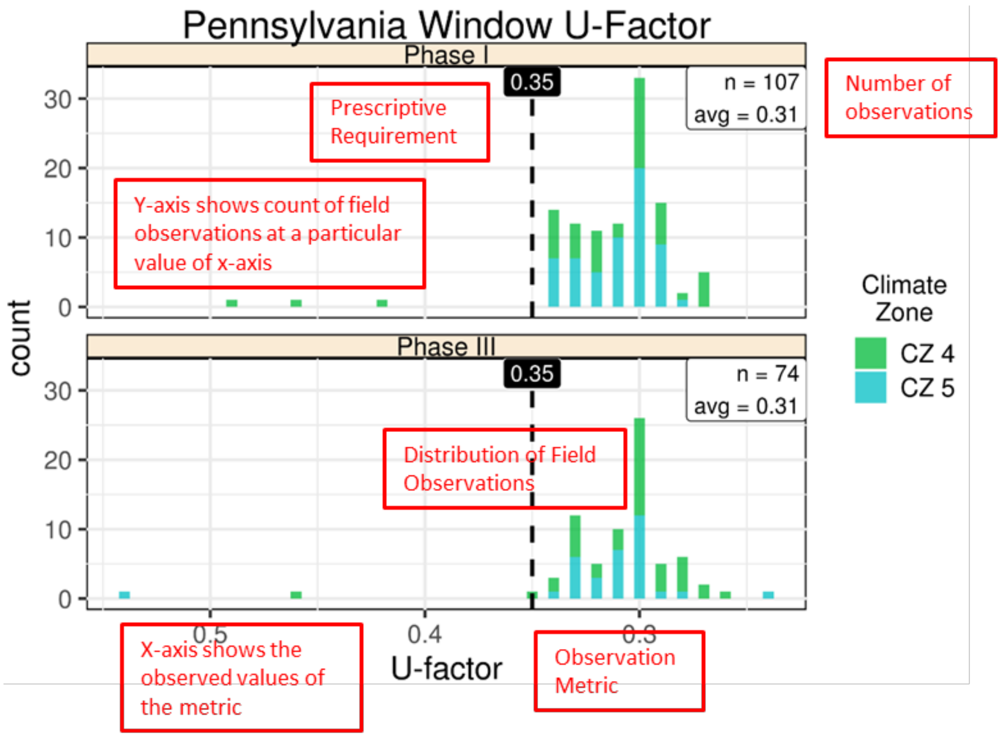

Figure 2.2. Sample Graph

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 CZ4 is 0.35)—values to the right-hand side of this line represent observations which are *better than code*. Values to the left-hand side represent areas for improvement.

2.3.2 Energy Analysis

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

Energy simulation was then conducted using the EnergyPlus™ software.[9] Each of the 1,500 models was run multiple times, to represent each combination of heating systems and foundation types commonly

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

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

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

2.3.3 Savings Analysis

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

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

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

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

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

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

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

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

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

2.4 Limitations

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

2.4.1 Applicability of Results

An inherent limitation of the study design is that the results (key item distributions, EUI, and measure-level savings) are statistically significant only at the state level. Other results, such as analysis based on climate zone level, reporting of non-key items (e.g., gas furnace efficiency), or further stratifications of the public data set are included and available but should not be considered statistically representative.

Both the Phase I and Phase III sample areas were limited to Eastern Pennsylvania (see Section 2.2.1). While the sample area covered just half the state, the results of the measure-level savings potential and EUI analysis were weighted by the number of permits issued for the entire state. This approach was agreed to by DOE and PSD during the analysis of Phase I data and was maintained during the Phase III analysis. It should be noted that Eastern Pennsylvania has CZ4A, CZ5A, and CZ6A, while Western Pennsylvania is mostly CZ5A and some CZ6A. In both cases, construction in CZ6A is small. DOE and PSD agreed to not sample CZ6A due to the small number of permits and assumed high cost of sampling this area. The implications of this assumption show up only in the EUI and measure level savings analysis.

For the EUI analysis (Section 3.2) and the measure level savings analysis (Section 3.3), results shown are only for CZ4A and CZ5A, as these were the two climate zones sampled. CZ6A was ignored for the same reason that it was not sampled - low construction volume.

For the measure level savings analysis, the number of permits used was that of the entire state, 16,371 at the time of the Phase I analysis according to the Census Bureau. This results in a simple extrapolation of the results from the sampled area (Eastern Pennsylvania) to the whole state.

2.4.2 Definition and Determination of Compliance

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

2.4.3 Sampling Substitutions

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

2.4.4 Site Access

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

2.4.5 Analysis Methods

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

2.4.6 Presence of Tradeoffs

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

2.5 Phase II Targeted Education and Training

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

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

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

For Pennsylvania, specific Phase II activities included:

- In-person training: PSD developed two half-day training programs including Residential Energy Plan Reviews in 15 Minutes or Less and Keys to Effective Energy Code Implementation. PSD garnered audiences primarily via code official associations and home builder associations and traveled within a roughly 200-mile radius of Philadelphia to give presentations, often in conjunction with association meetings. Working with code enforcement and industry associations was a successful way to reach audiences. There were 887 participants at 44 events/seminars.
- Circuit rider[13]: Circuit rider visits involved an energy expert meeting with an individual head of a building department or a small group of building department staff including plan reviewers and inspectors. Visits included interviews to assess existing permit applications and associated forms, plan review process, and inspection processes followed by guided plan reviews and recommendations for process improvements to enable more thorough enforcement of the identified problem areas. In many cases, these visits also included an in-field component involving mock inspections and blower door and duct tightness testing demonstrations. These sessions offer a very high level of participant

[13] A *circuit rider* is an individual with subject matter expertise who mobilizes to serve multiple jurisdictions across a given geographic area (e.g., providing insight, expertise and training on compliance best practices).

engagement and leave participants with specific action items. The circuit rider made 28 visits and had sessions with 161 people.

- Online training: PSD supplemented in-person training with one-hour webinars presented roughly monthly. This was a way to reach audiences interested in shorter programs that could be watched from their own offices. This was also a way to reach audiences that might not be members of associations. These sessions provided additional training opportunities at a relatively low cost.
- Overall, 12 webinars were held with over 204 attendees. Webinar topics included: PA Energy Code Field Study Results; Using the E-CODE Assistant; Builders, Code Officials and Raters Working Together; Blower Door Testing; Duct Leakage Testing; HVAC Equipment Sizing; Insulation Installation; REScheck and the Performance Path; Energy Code Plan Reviews; Test Your Energy Code Knowledge; Important Air Barrier Details; and Going Beyond Code: Above Code Programs.
- Other activities: PSD completed three custom training/technical assistance visits including a performance testing demonstration with representatives from two different third-party inspection agencies and one builder team for a combined attendance of 18 people. PSD also developed a template for building plans and details to improve the level of compliance documentation while saving time for plan reviewers since all necessary energy code information is in one place. A postcard was developed to highlight the health and safety risks of leaky ducts, including a simple three-step process to ensure safety and compliance. Almost 500 postcards were mailed to code officials and builders. Over 30 newsletters were developed and sent.

2.6 Phase III Field Study and Analysis

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

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

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

3.0 State Results

3.1 Field Observations

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.

3.1.1 Key Items

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

The following key items were found applicable within the state:

1. Envelope tightness (ACH at 50 Pascals)
2. Windows (U-factor & SHGC)
3. Wall insulation (assembly U-factor)
4. Ceiling insulation (R-value)
5. Lighting (% high-efficacy)
6. Foundations – basement walls and floors (assembly U-factor)
7. Duct tightness (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.

3.1.1.1 Envelope Tightness

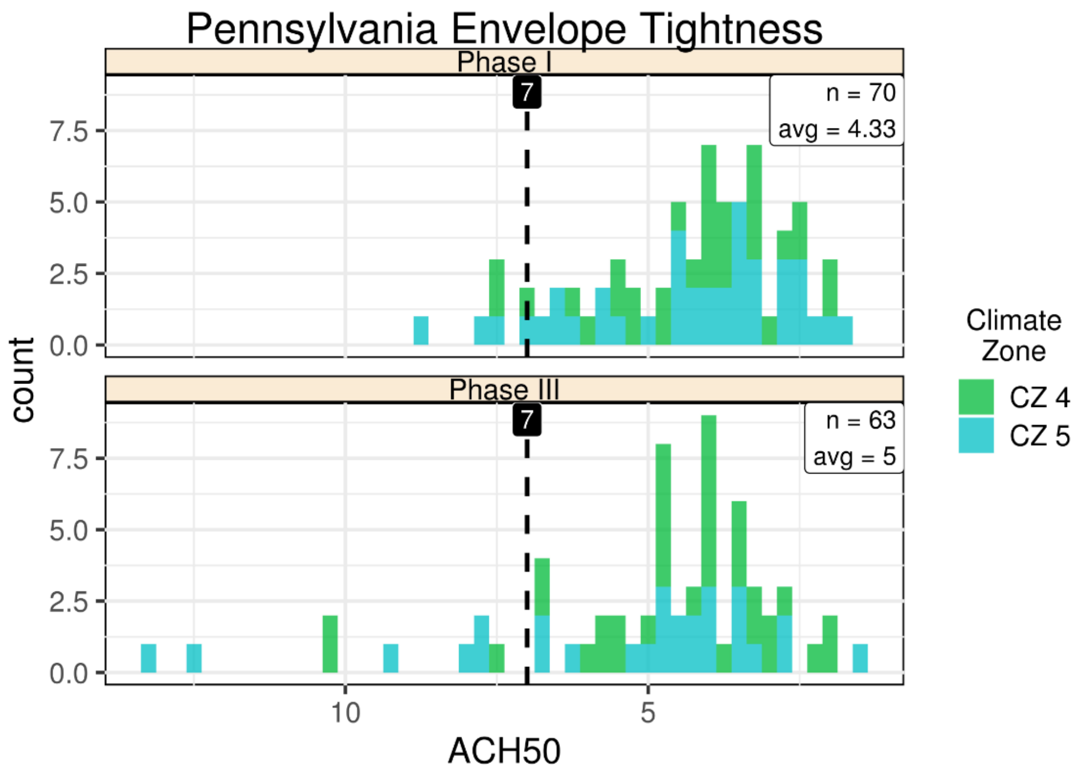

Figure 3.1. Comparison of Phase I and Phase III Envelope Tightness for Pennsylvania

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

Envelope Tightness (ACH50)	CZ4	PA Phase I CZ5	Statewide	CZ 4	PA Phase III CZ5	Statewide
Requirement	7	7	7	7	7	7
Observations						
Number	31	39	70	35	28	63
Range	1.9 to 7.6	1.7 to 8.9	1.7 to 8.9	2.1 to 10.4	1.5 to 13.2	1.5 to 13.2
Average	4.3	4.4	4.3	4.6	5.4	5.0
Compliance Rate	29 of 31 (94%)	36 of 39 (92%)	65 of 70 (93%)	32 of 35 (91%)	22 of 28 (79%)	54 of 63 (86%)

- **Interpretations:**
  - Envelope air tightness was achieved at a high rate in Phase I, with an average of 4.3 ACH50 and an overall compliance rate of 93%. In Phase III, both the average and the compliance rate dropped – due mostly to CZ5.
  - In Phase I, 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

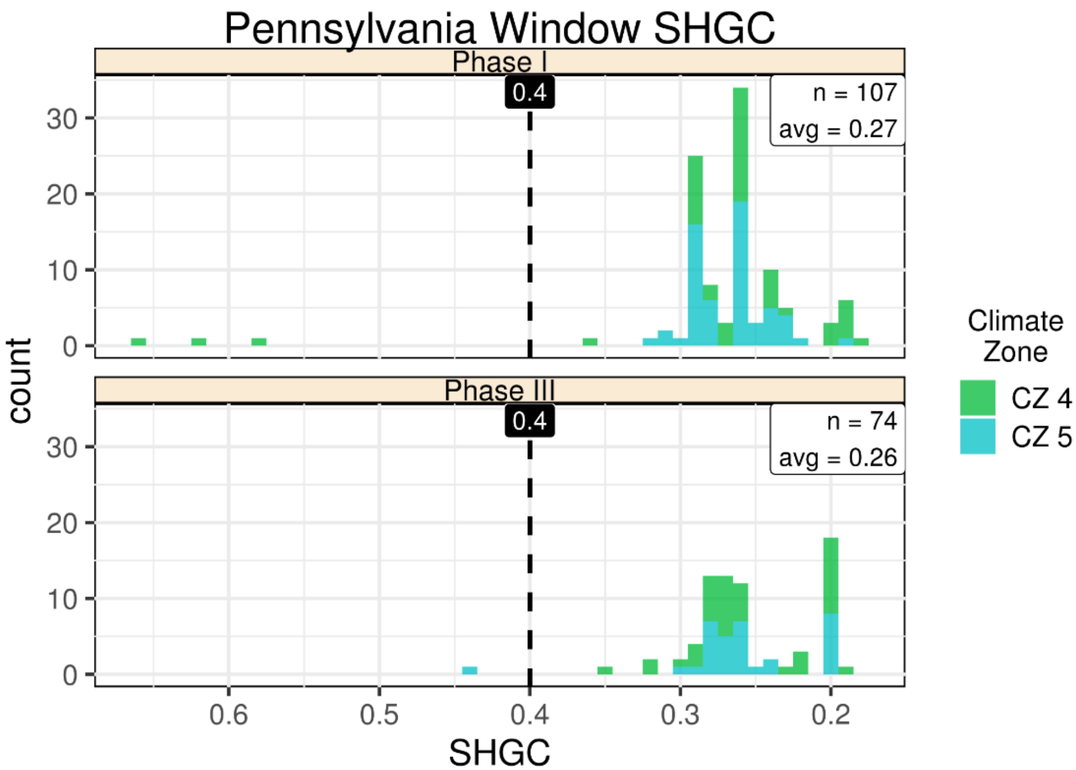

Figure 3.2. Comparison of Phase I and Phase III Window SHGC for Pennsylvania

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

Window SHGC	CZ4	Phase I CZ5	Statewide	CZ 4	Phase III CZ5	Statewide
Requirement	NA	NA	NA	NA	NA	NA
Observations						
Number	48	59	107	41	33	74
Range	0.66 to 0.18	0.32 to 0.19	0.66 to 0.18	0.35 to 0.19	0.44 to 0.2	0.44 to 0.19
Average	0.28	0.27	0.27	0.25	0.26	0.26
Compliance Rate	NA	NA	NA	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 in Phase I and 0.2 to 0.29 in Phase III.

3.1.1.3 Window U-Factor

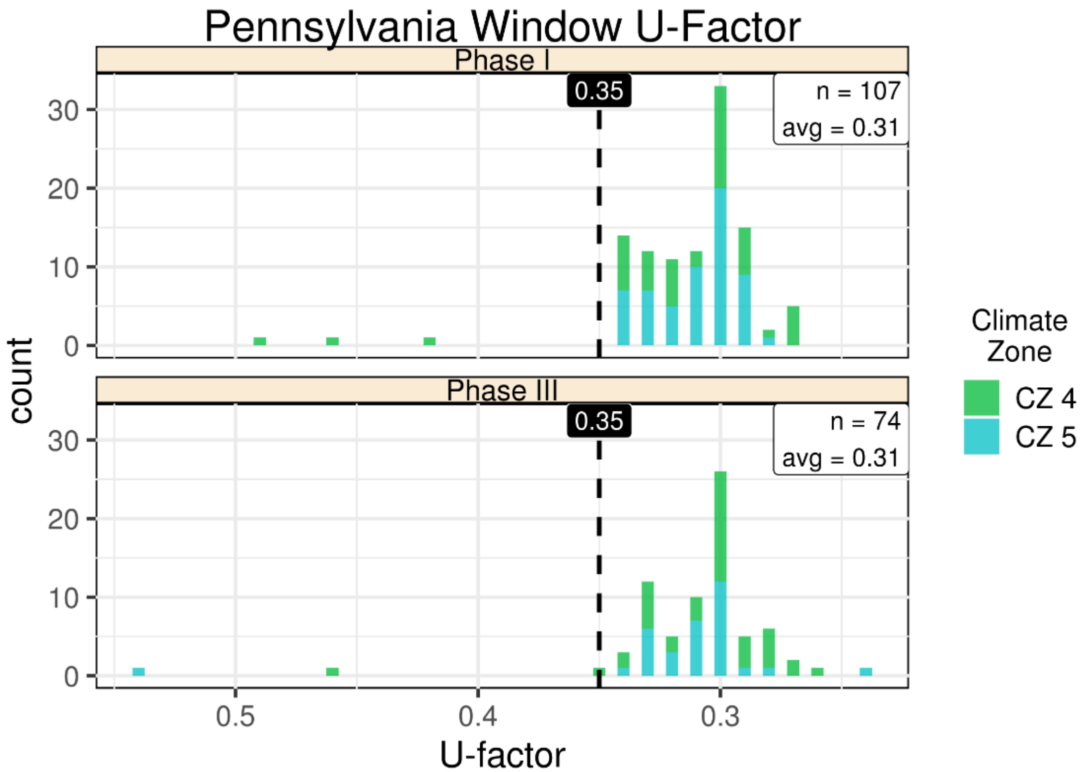

Figure 3.3. Comparison of Phase I and Phase III Window U-Factors for Pennsylvania

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

		Phase I			**Phase III**	
Window U	**CZ4**	**CZ5**	**Statewide**	**CZ 4**	**CZ5**	**Statewide**
Requirement	0.35	0.35	0.35	0.35	0.35	0.35
Observations						
Number	48	59	107	41	33	74
Range	0.49 to 0.27	0.34 to 0.28	0.49 to 0.27	0.46 to 0.26	0.54 to 0.24	0.54 to 0.24
Average	0.32	0.31	0.31	0.31	0.31	0.31
Compliance Rate	45 of 48 (94%)	59 of 59 (100%)	104 of 107 (97%)	40 of 41 (98%)	32 of 33 (97%)	72 of 74 (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

Wall insulation data is presented in terms of both frame cavity insulation and overall assembly performance in order to capture the conditions seen in the field. The cavity insulation data is based on the observed value (R-value), as printed on the manufacturer label and installed in the home. While cavity insulation is important, it is not fully representative of wall assembly performance, since this data point alone does not account for other factors that can have a significant effect on the wall system such as combinations of cavity and continuous insulation and insulation installation quality (IIQ). Therefore, wall insulation is also presented from a second perspective—overall assembly performance (U-factor).[1]

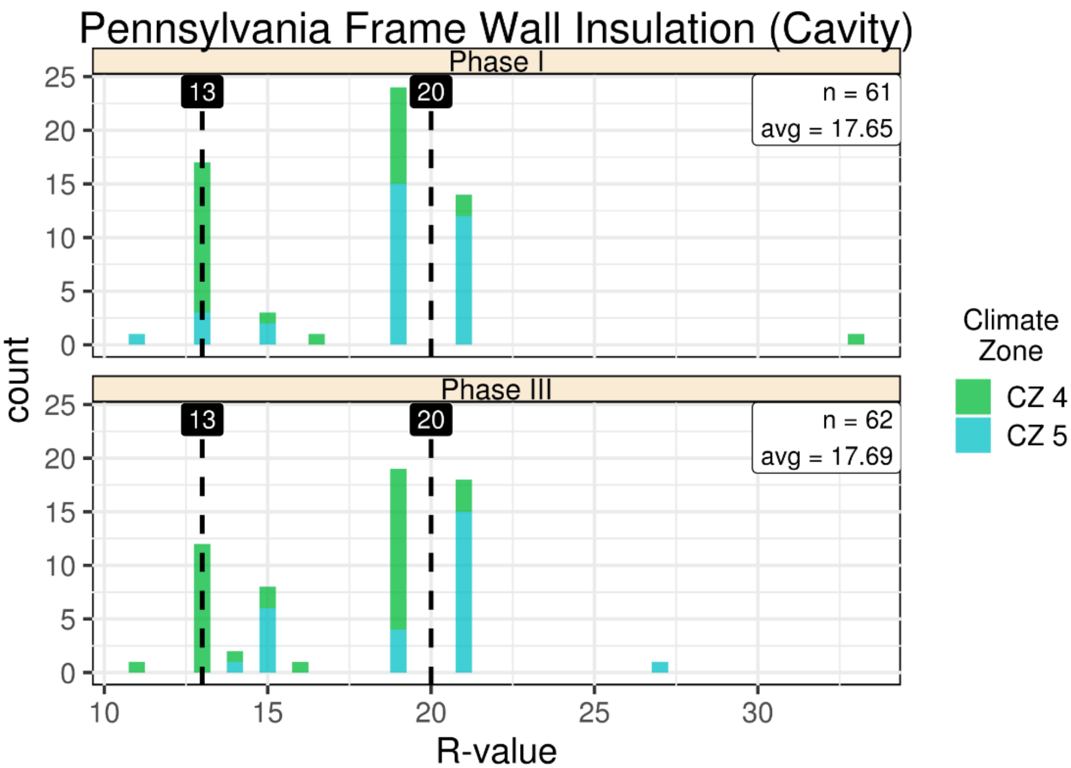

Figure 3.4. Comparison of Phase I and Phase III Wall (Cavity) R-Values for Pennsylvania

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

[1] Note that there is an apparent discrepancy between the number of wall insulation observations shown for Phase I in Figure 3.4 and Table 3.4, Figure 3.5, and Table 3.5. This apparent discrepancy arises because one home in Phase I had no cavity insulation but had R-30 continuous insulation. Figure 3.4 only shows cavity insulation observations, and the R-0 is not included. Table 3.4, Figure 3.5, and Table 3.5 include walls with both cavity and continuous insulation.

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

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

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

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Above Grade Wall Observations	20 / 2	40 / 60	2 / 0	**62 / 62**
Above Grade Percentages	32% / 3%	65% / 97%	3% / 0%	**100% / 100%**

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

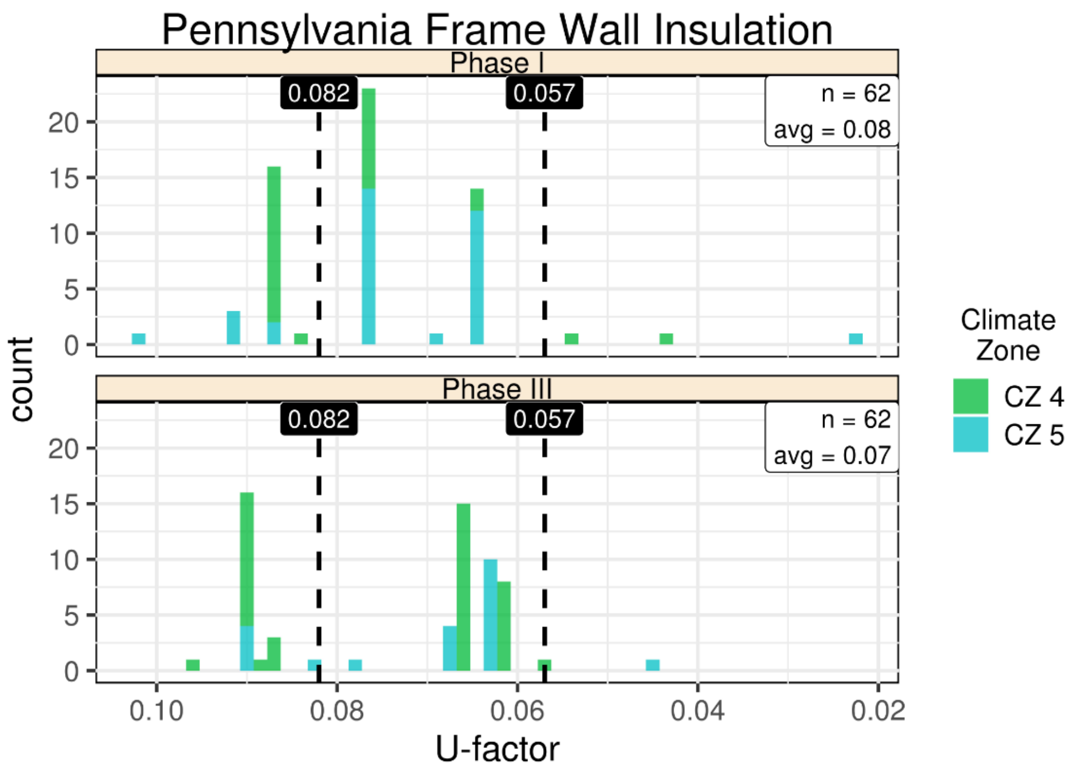

Figure 3.5. Comparison of Phase I and Phase III Wall U-Factors for Pennsylvania

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

		Phase I			Phase III	
Wall U	**CZ4**	**CZ5**	**Statewide**	**CZ 4**	**CZ5**	**Statewide**
Requirement	U-0.082	U-0.057	0.082 in CZ4 and 0.057 in CZ5	U-0.082	U-0.057	0.082 in CZ4 and 0.057 in CZ5
Observations						
Number	28	34	62	41	21	62

Range	U-0.082 to U-0.043	U-0.105 to U-0.020	U-0.105 to U-0.020	U-0.096 to U-0.057	U-0.089 to U-0.045	U-0.096 to U-0.045
Average	U-0.080	U-0.072	U-0.076	U-0.75	U-0.070	U-0.,073
Compliance Rate	13 of 28 (46%)	1 of 34 (3%)	14 of 62 (23%)	24 of 41 (59%)	1 of 21 (5%)	25 of 62 (40%)

- **Interpretations:**
  - Overall wall U-factor compliance nearly doubled, from 23% in Phase I to 40% in Phase III.
  - Compliance is better in CZ 4A than in CZ 5A in both Phases.
  - Table 3.4 indicates that IIQ is a major factor in these results, with IIQ Grade II accounting for 97% of the Phase III observations, but only 65% of the Phase I observations.

3.1.1.5 Ceiling Insulation

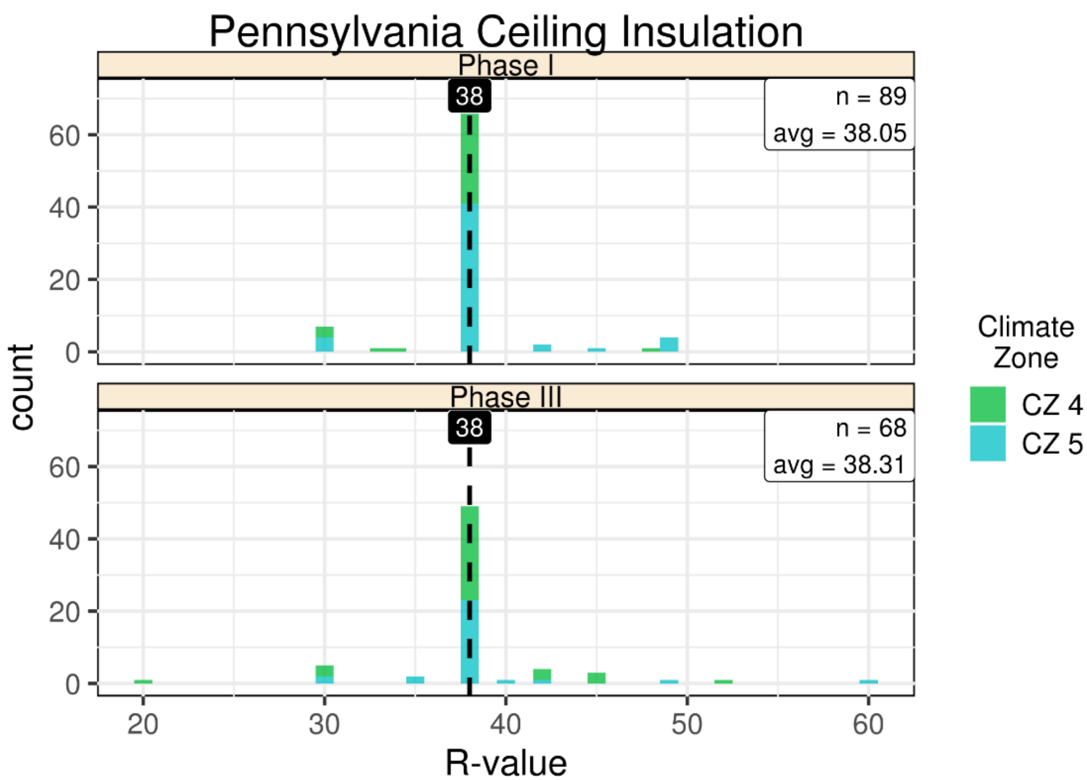

Figure 3.6. Comparison of Phase I and Phase III Ceiling R-Values for Pennsylvania

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

		Phase I			Phase III	
Ceiling R	**CZ4**	**CZ5**	**Statewide**	**CZ 4**	**CZ5**	**Statewide**
Requirement	R-38	R-38	R-38	R-38	R-38	R-38
Observations						
Number	27	52	89	37	31	68
Range	R-30 to R-48	R-30 to R-49	R-30 to R-49	R-20 to R-52	R-30 to R-60	R-20 to R-60
Average	R-37.4	R-38.5	R-38.0	R-38.1	R-38.5	R-38.3

Compliance Rate	32 of 37 (86%)	48 of 52 (92%)	80 of 89 (90%)	33 of 37 (89%)	27 of 31 (87%)	60 of 68 (88%)

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

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

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Roof Cavity Observations	47 / 12	40 / 51	2 / 5	**89 / 68**
Roof Cavity Percentages	53% / 18%	45% / 75%	2% / 7%	**100% / 100%**

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

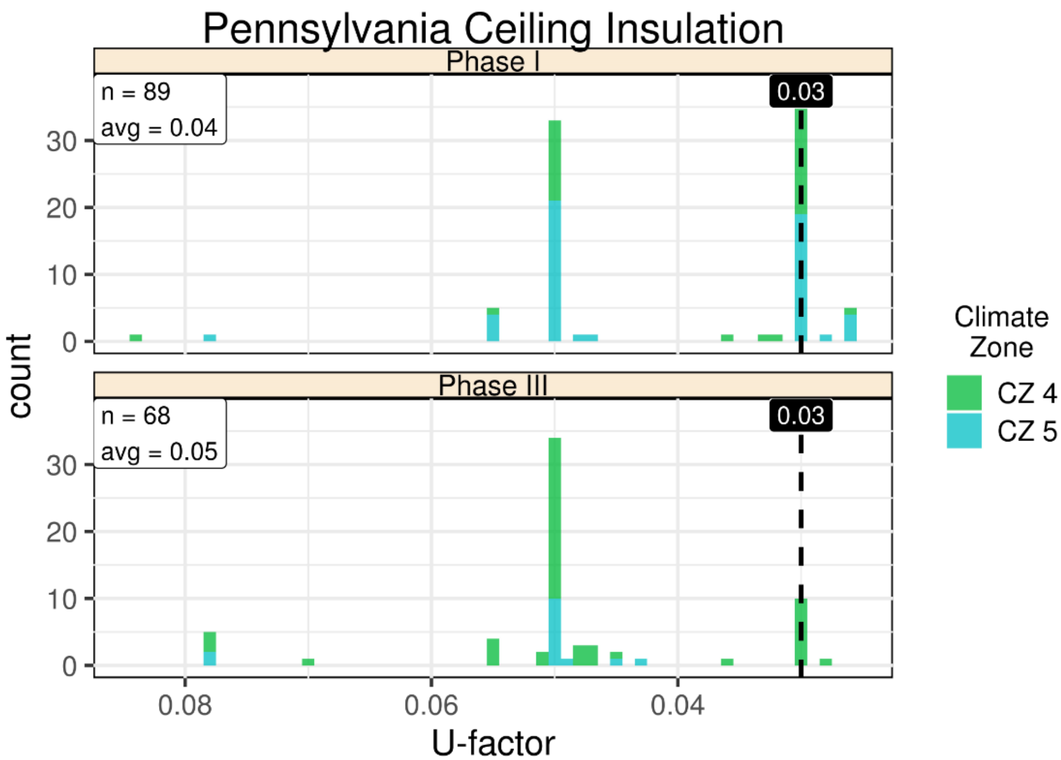

Figure 3.7. Comparison of Phase I and Phase III Ceiling U-Factors for Pennsylvania

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

Ceiling U	Phase I CZ4	Phase I CZ5	Phase I Statewide	Phase III CZ 4	Phase III CZ5	Phase III Statewide
Requirement	U-0.03	U-0.03	U-0.03	U-0.03	U-0.03	U-0.03
Observations						
Number	37	52	89	53	15	68
Range	U-0.084 to U-0.026	U-0.078 to U-0.026	U-0.084 to U-0.026	U-0.078 to U-0.028	U-0.078 to U-.043	U-0.078 to U-0.028
Average	U-0.039	U-0.041	U-0.040	U-0.047	U-0.053	U-0.048
Compliance Rate	20 of 37 (54%)	24 of 52 (46%)	44 of 89 (49%)	11 of 53 (21%)	0 of 15 (0%)	11 of 68 (16%)

- **Interpretations:**
  - When considering R-values, the observations look good with the average R-value at the code requirement of R-38 in both phases.
  - When considering U-factors, however, the significant effect that IIQ can have on the overall assembly performance is evident. The average U-factor increased, and the compliance rate decreased between Phase I to Phase III due to a deterioration in IIQ observations. Significant savings opportunities remain in this area.[1]

[1] Ceiling insulation was not marked as a focal point for education for Phase II due to Ceiling R-value compliance not meeting the 15% non-compliance cutoff for inclusion in the Phase I measure-level savings analysis. By the time the PA Phase III analysis was done, DOE had changed to using ceiling U-factors rather than R-values for the cutoff. Had that been the case prior to the Phase I analysis, ceiling insulation would have been a focal point in Phase II. To provide a more complete comparison between Phase I and Phase III, DOE included ceiling insulation in the above table as well as in a revised Phase I measure-level savings estimate.

3.1.1.6 Lighting

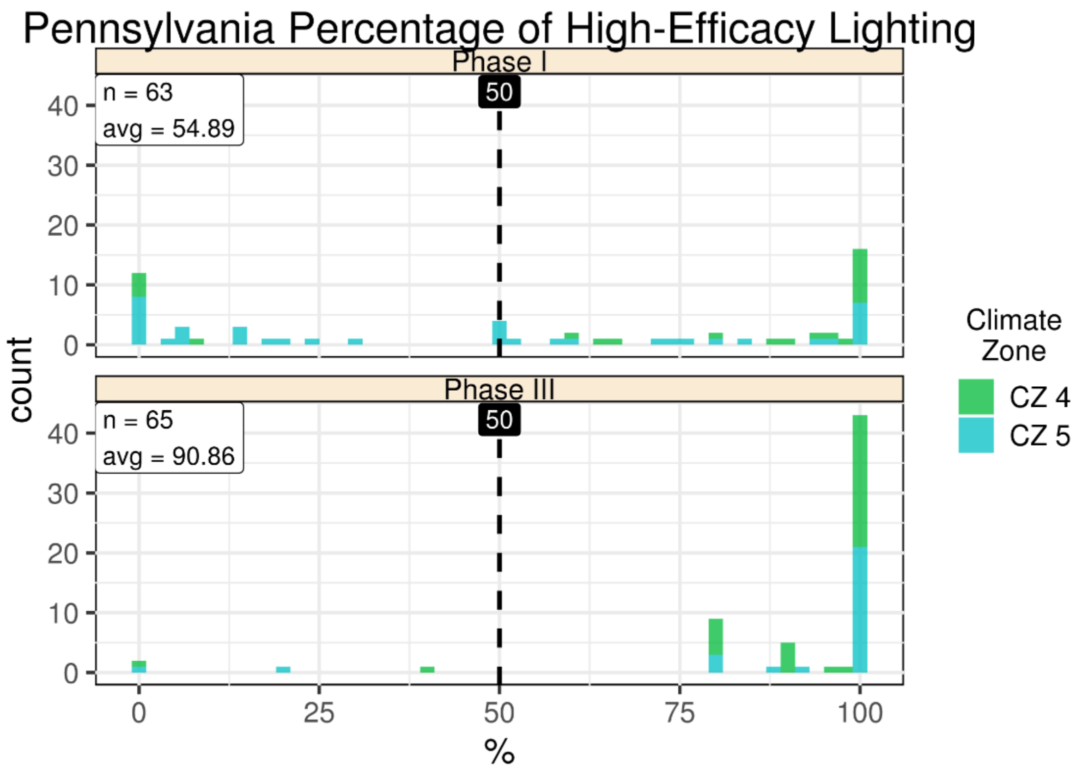

Figure 3.8. Comparison of Phase I and Phase III High-Efficacy Lighting Percentages for Pennsylvania

Table 3.9. Pennsylvania High-Efficacy Lighting in Phase I and Phase III

Lighting	CZ4	Phase I CZ5	Statewide	CZ 4	Phase III CZ5	Statewide
Requirement	50	50	50	50	50	50
Observations						
Number	23	40	63	37	28	65
Range	0 to 100	0 to 100	0 to 100	0 to 100	0 to 100	0 to 100
Average	71.6	45.3	54.9	90.9	90.8	90.9
Compliance Rate	18 of 23 (78%)	21 of 40 (53%)	39 of 63 (62%)	35 of 37 (95%)	26 of 28 (93%)	61 of 65 (94%)

- **Interpretations:**
  - A little more than half of the Phase I field observations were observed to meet the requirement; a much lower number than expected. This represented an area of savings potential and was a focus of Phase II education and training activities.
  - In Phase III, nearly all of the field observations meet or exceed the requirement, suggesting the increased attention in education and training activities was successful.

3.1.1.7 Foundation Assemblies

In Phase I, there were two predominant foundation types observed in Pennsylvania, heated basements and floors over unheated basements. There were also a small number of slabs-on-grade in both Phase I and Phase III. 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 IIQ, as observed in the field. The U-factors are binned to reduce the number of bars in the chart as individual U-factor observations may be only slightly different. For slabs, only an R-value graph is shown.

While initially combined into a single key item (i.e., foundation assemblies), 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 was 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 Walls

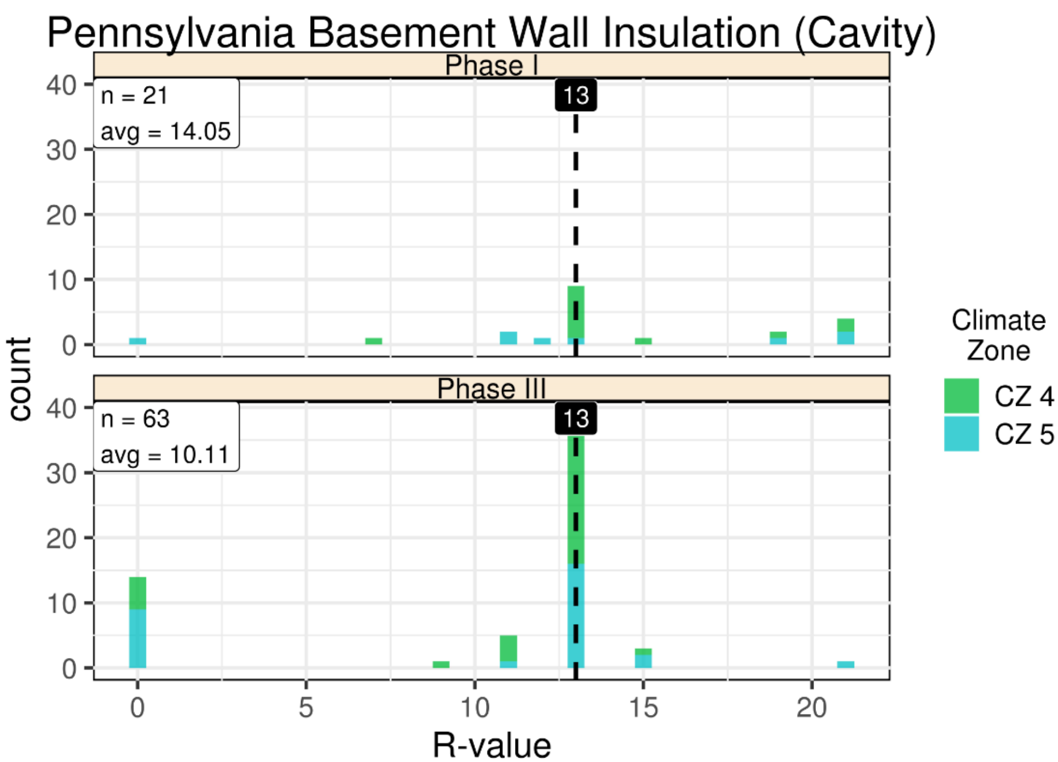

Figure 3.9. Comparison of Phase I and Phase III Basement Wall Cavity R-Values for Pennsylvania

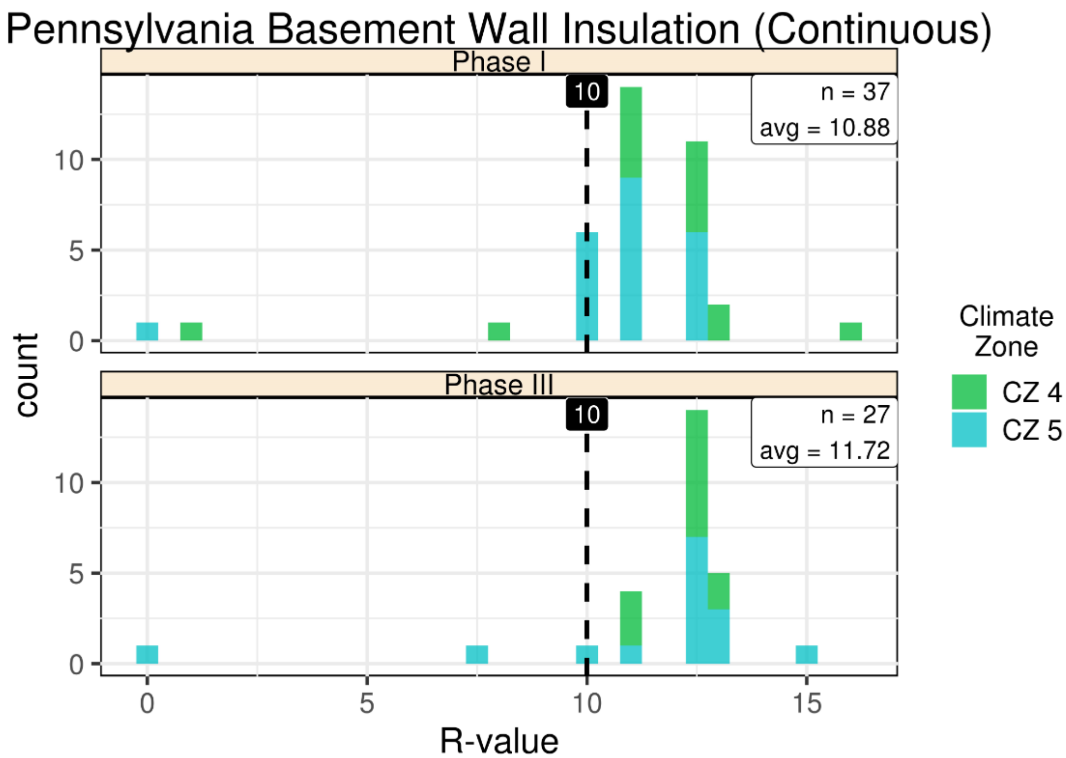

Figure 3.10. Comparison of Phase I and Phase III Basement Wall Continuous R-Values for Pennsylvania

Table 3.10 shows the number and percentage of IIQ observations by grade for basement wall insulation for Phase I and Phase III. Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.11.

Table 3.10. Basement Wall IIQ Comparison between Phase I and Phase III for Pennsylvania

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Basement Wall Observations	32 / 7	14 / 54	0 / 2	**46 / 63**
Basement Wall Percentages	70% / 11%	30% / 86%	0% / 3%	**100% / 100%**

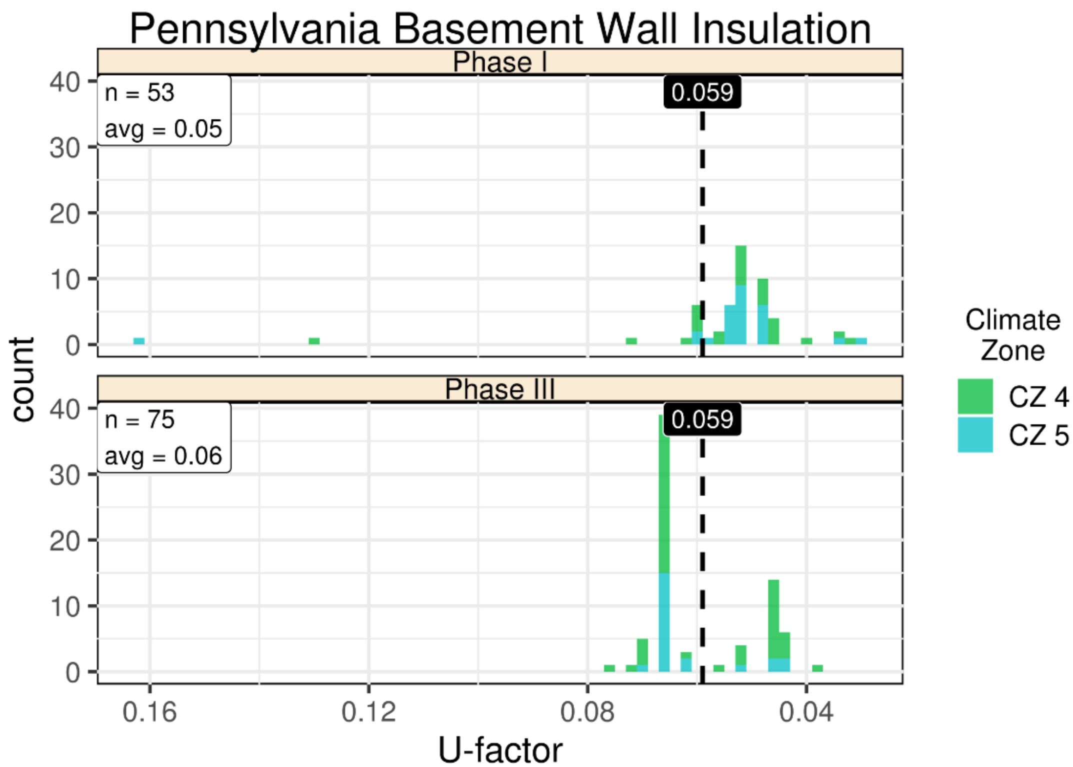

Figure 3.11. Comparison of Phase I and Phase III Basement Wall U-Factors for Pennsylvania

Table 3.11. Pennsylvania Basement Wall U-Factors in Phase I and Phase III

Basement Wall U	CZ4	Phase I CZ5	Statewide	CZ 4	Phase III CZ5	Statewide
Requirement	U-0.059	U-0.059	U-0.059	U-0.059	U-0.059	U-0.059
Observations						
Number	26	27	53	52	23	75
Range	U-0.130 to U-0.032	U-0.163 to U-0.029	U-0.130 to U-0.029	U-0.075 to U-0.039	U-0.070 to U-0.044	U-0.075 to U-0.039
Average	U-0.054	U-0.054	U-0.054	U-0.058	U-0.061	U-0.059
Compliance Rate	19 of 26 (73%)	23 of 27 (85%)*	42 of 53 (79%)	21 of 52 (40%)	5 of 23 (22%)	26 of 75 (35%)

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

- **Interpretations:**
  - When considering cavity R-values, the average R-value declined between Phase I and Phase III.
  - IIQ has a significant effect on overall assembly performance as seen in the U-factor results. The percentage of Grade II and Grade III observations increased from 30% in Phase I to 89% in Phase III. Significant savings opportunities remain in this area.

Floors

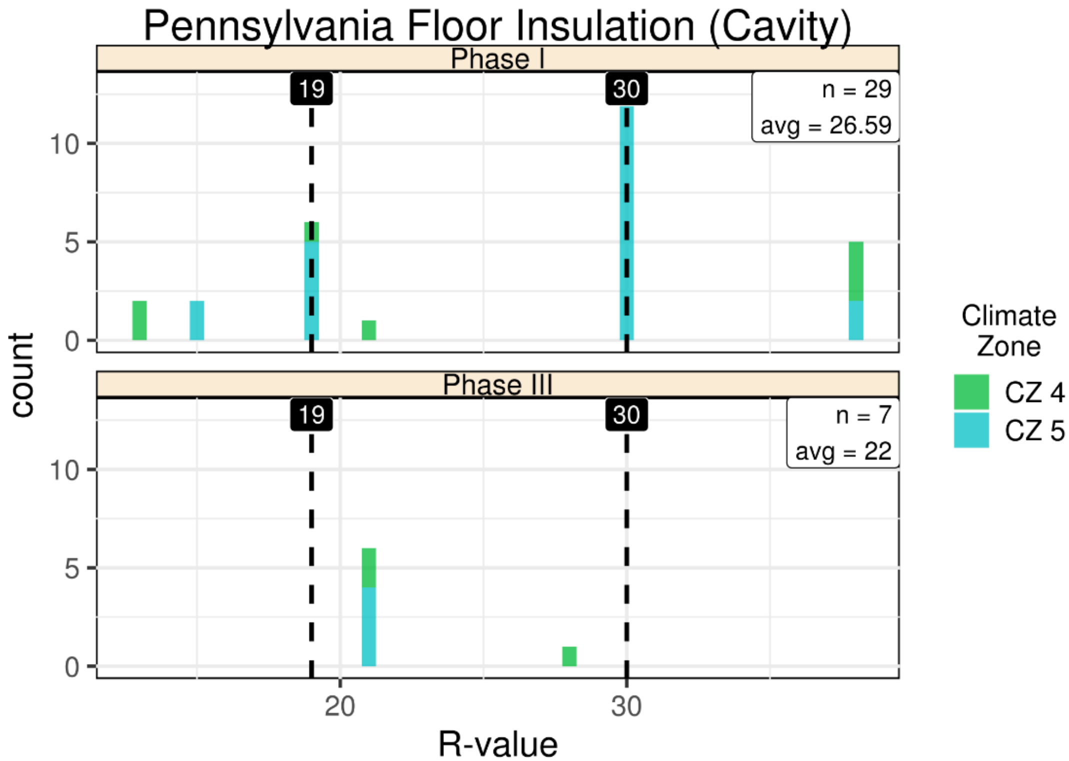

Figure 3.12. Comparison of Phase I and Phase III Floor Cavity R-Values for Pennsylvania

Table 3.12 shows the number and percentage of IIQ observations by grade for floor insulation for Phase I and Phase III. Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Figure 3.13.

Table 3.12. Floor IIQ Comparison between Phase I and Phase III for Pennsylvania

Assembly	Ph I / Ph III Grade I	Ph I / Ph III Grade II	Ph I / Ph III Grade III	Ph I / Ph III Total Observations
Floor Observations	8 / 0	18 / 7	2 / 0	**28 / 7**
Floor Percentages	29% / 0%	65% / 100%	7% / 0%	**100% / 100%**

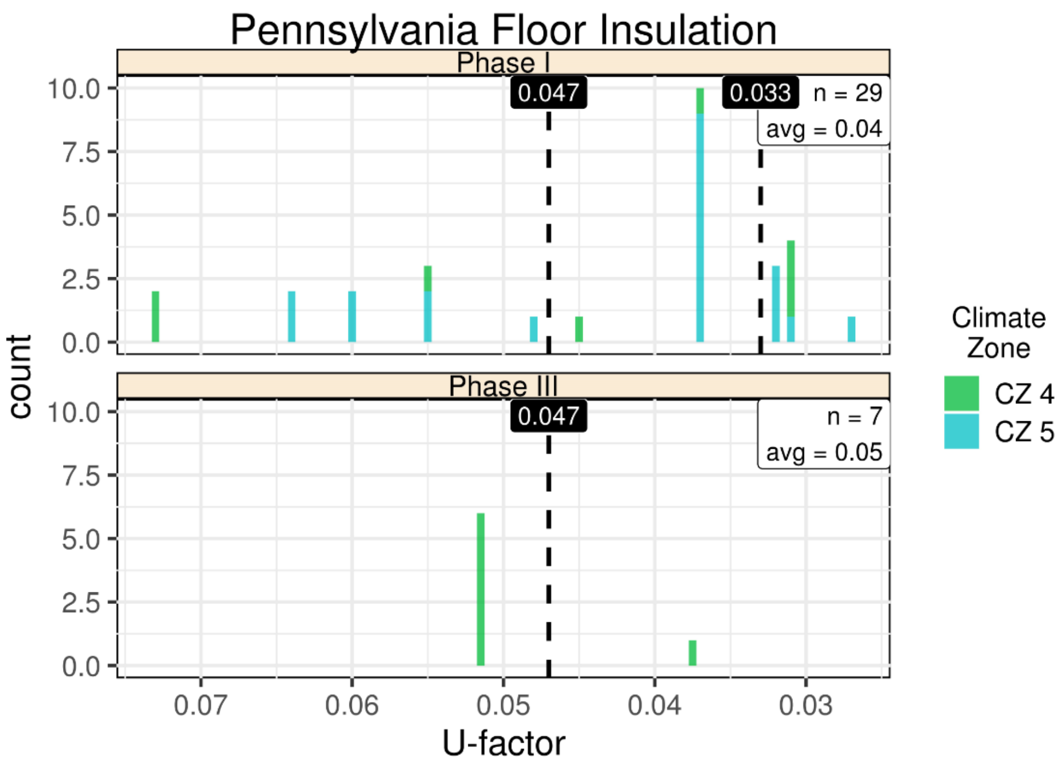

Figure 3.13. Comparison of Phase I and Phase III Floor U-Factors for Pennsylvania

Table 3.13. Pennsylvania Floor U-Factors in Phase I and Phase III

Floor U	CZ4	Phase I CZ5	Statewide	CZ 4	Phase III CZ5	Statewide
Requirement	U-0.047	U-0.033	U-0.047 for CZ4 and U-0.033 for CZ5	U-0.047	U-0.033	U-0.047 for CZ4 and U-0.033 for CZ5
Observations						
Number	8	21	29	7	0	7
Range	U-0.073 to U-0.031	U-0.060 to U-0.027	U-0.073 to U-0.027	U-0.052 to U-0.038	NA	U-0.052 to U-0.038
Average	U-0.047	U-0.042	U-0.044	U-0.050	NA	U-0.050
Compliance Rate	5 of 8 (63%)	4 of 21 (19%)	9 of 29 (31%)	1 of 7 (14%)	NA	1 of 7 (14%)

- **Interpretations:**
  - The number of observations of floor insulation in Phase III is only seven compared to 29 in Phase I.
  - R-value observations appear to decline between Phase I and Phase III, as well as overall U-factor observations.
  - When considering U-factors, the effect of IIQ is seen. The percentage of Grade II and Grade III observations increased from 72% in Phase I to 100% in Phase III.

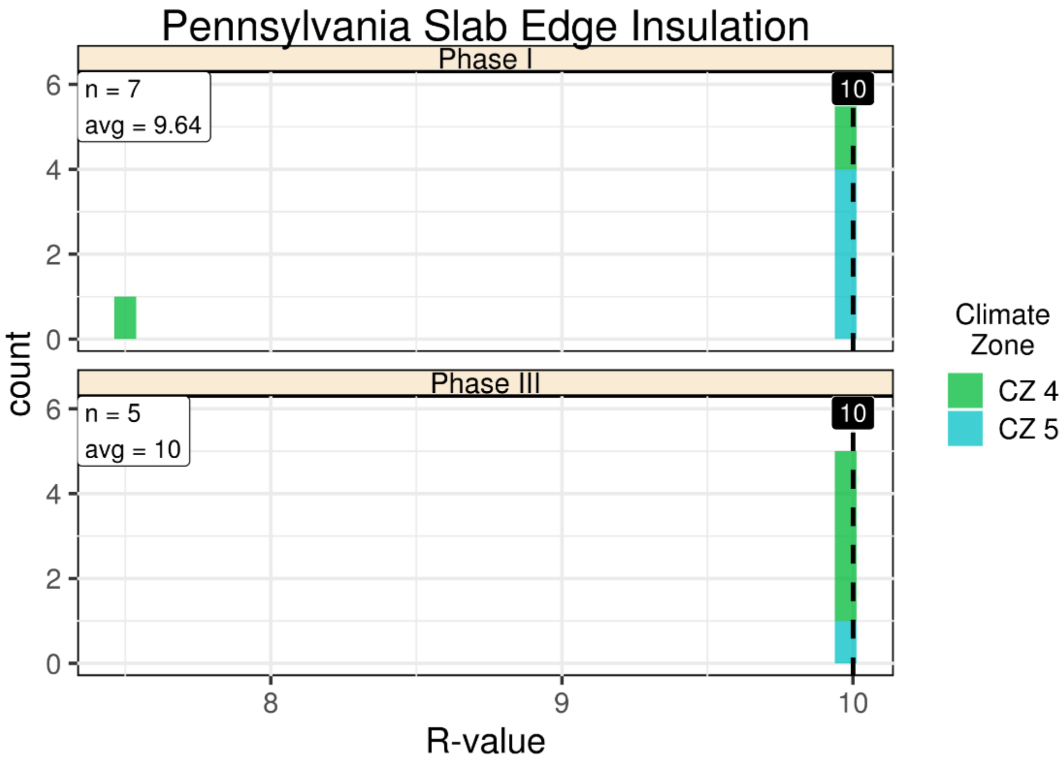

Figure 3.14. Comparison of Phase I and Phase III Slab R-Values for Pennsylvania

Table 3.14. Pennsylvania Slab R-Values in Phase I and Phase III

Slab R	PA Phase I	PA Phase III
Requirement	10	10
Observations		
Number	7	5
Range	R-0 to R-10	R-10
Average	R-9.64	R-10
Compliance Rate	6 of 7 (86%)	5 of 5 (100%)

- **Interpretations:**
  - The majority of slab edge insulation observations complied in Phase I; with one observation having no slab insulation.
  - In Phase III, all observations met the requirement.

3.1.1.8 Duct Tightness

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

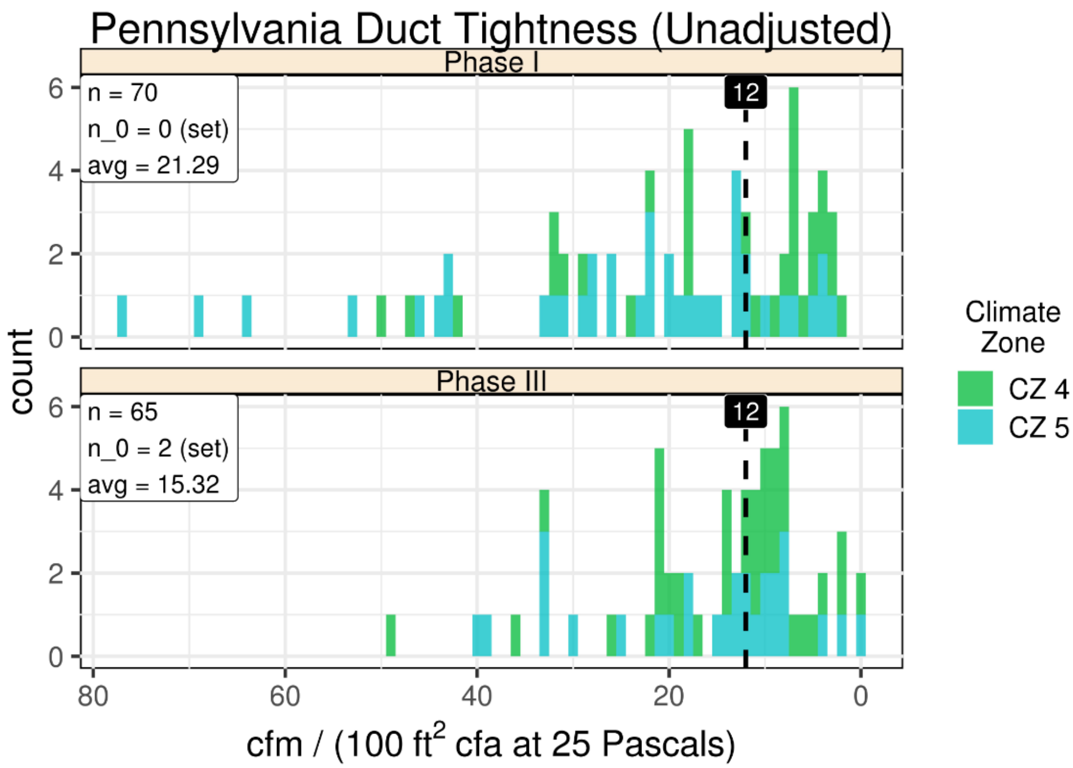

Figure 3.15. Comparison of Phase I and Phase III Duct Tightness Values for Pennsylvania[1]

Table 3.15. Pennsylvania Duct Tightness Values in Phase I and Phase III (unadjusted)

Duct Tightness	Phase I CZ4	Phase I CZ5	Phase I Statewide	Phase III CZ 4	Phase III CZ5	Phase III Statewide
Requirement	12	12	12	12	12	12
Observations						
Number	30	40	70	37	28	65
Range	2.4 to 50	2.8 to 77.1	2.4 to 77.1	0 to 48.8	0 to 40.0	0 to 48.8
Average	13.8	21.8	21.3	14.3	16.6	15.3
Compliance Rate	17 of 30 (57%)	9 of 40 (23%)	26 of 70 (37%)	20 of 37 (54%)	11 of 28 (39%)	31 of 65 (48%)

[1] Note that Figure 3.15 and Table 3.15 show two unadjusted duct tightness values of 0 for Phase III, one in CZ4 and one in CZ5; which would indicate a perfectly sealed duct system, which is unlikely in reality. A check of the raw data files for these two homes indicate no comments for the 0 values. A more detailed look at the photos of the home conducted after this analysis indicated that one of the homes had 4 mini split heat pump units and therefore no ducts, while the other home appears to have a duct system but the location was marked "not observable". Therefore, these homes should have been listed as "NA" and "Not observable" in the data collection forms, respectively. The inclusion of these two values does slightly lower the overall average duct leakage for both unadjusted and adjusted duct tightness.

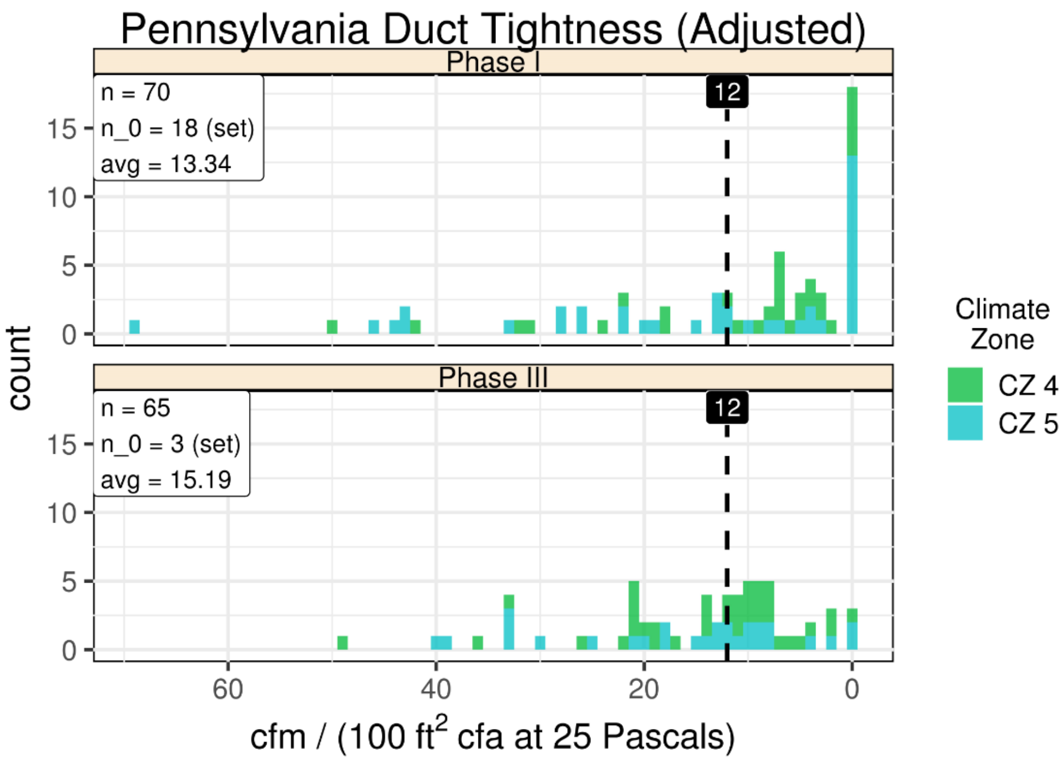

Figure 3.16. Comparison of Phase I and Phase III Duct Tightness Values for Pennsylvania

Table 3.16. Pennsylvania Duct Tightness Values in Phase I and Phase III (Adjusted)

Duct Tightness (Adjusted)	CZ4	Phase I CZ5	Statewide	CZ 4	Phase III CZ5	Statewide
Requirement	4	4	4	4	4	4
Observations						
Number	30	40	70	37	28	65
Range	0 to 50	0 to 69	0 to 69	0 to 48.8	0 to 40.0	0 to 48.8
Average	11.5	14.7	13.3	14.6	16.3	15.2
Compliance Rate	22 of 30 (73%)	22 of 40 (55%)	44 of 70 (63%)	20 of 37 (54%)	11 of 28 (39%)	31 of 65 (48%)

- **Interpretations:**
  - The average adjusted duct leakage increased and compliance decreased between Phase I and Phase III.
  - The maximum duct leakage observed went down between phases, indicating that rather than a problem of a few leaky ducts, there may be a systemic problem.

The project team noted in Phase I 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 tightness 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 tightness 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.

3.1.2 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, in addition to the key items alone.

The following represents a summary of this data and outlines some of the more significant findings, in many cases including the observation or compliance rate associated with the specified item. A larger selection of the additional data items collected as part of the state field study is contained in Appendix C. The full data set is also available on the DOE Building Energy Codes Program website.[1]

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

3.1.2.1 Average Home

Table 3.17. Average Home

Home Statistics	Phase I	Phase III
Average square footage (ft^2)	2882	2645
Number of Stories	2.13	2.06

3.1.2.2 Compliance

- Almost all homes (98%) were permitted under the 2009 IECC in Phases I and III. Two percent selected the Pennsylvania Alternative in Phase I and 0% in Phase III. In Phase III, 2% selected the 2006 IECC.
- Seven homes were noted as participating in an above-code program in Phase I and none in Phase III.

3.1.2.3 Envelope

Table 3.18. Envelope

Requirement	Phase I	Phase III
Profile		
Walls	All wood-framed with mix of 4" (56%) and 6" (44) (n=132)	All wood-framed with mix of 4" (71%) and 6" (29%) (n= 59)
Foundations	n= 171	n= 134

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

Basement	75%[1]	82%
Slab-on-grade	25%	16%
Crawl space	0%	1%
Insulation labeled	96% (n=49)	42% (n=48)
Lighting fixtures sealed	84% (n=31)	NA
Utility penetrations sealed	88% (n=52)	91% (n=11)
Attic access openings sealed	73% (n=67)	95% (n=31)
Envelope areas behind bathroom tubs and showers	57% (n=28)	NA
Knee walls	33% (n=21)	67% (n=9)

3.1.2.4 Duct & Piping Systems

Table 3.19. Duct and Piping Systems

Requirement	Phase I	Phase III
Profile		
Supply ducts located within conditioned space (percentage of duct system)	76% (n=96)	73% (n=15)
Return ducts located within conditioned space (percentage of duct system)	78% (n=95)	73% (n=8)
Supply ducts entirely within conditioned space (percentage of homes and number)	35% (34 homes)	7% (15 homes)
Return ducts entirely within conditioned space (percentage of homes and number)	48% (46 homes)	25% (8 homes)
Duct Insulation	R-5.7 (n=51)	R-5.8 (n=21)
Pipe Insulation	R-3.3 (n=41)	NA (n=0)
Air handlers sealed	96% (n=58)	34% (n=35)
Filter boxes sealed	79% (n=100)	34% (n= 38)

Successes and Improvement

The percentage of supply and return ducts entirely in conditioned space dropped sharply from Phase I to Phase III. The percentage of air handlers and filter boxes sealed also dropped from Phase I to Phase III.

3.1.2.5 HVAC Equipment

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

[1] Almost all basements observed in the study were conditioned (90%) in Phase I and 66% in Phase III.

Table 3.20. HVAC Equipment

Requirement	Phase I	Phase III
Profile		
Heating equipment type	Mostly gas furnaces (n=116, 110 gas furnace, 6 electric heat pump)	Primarily gas furnaces (n=54, 49 gas furnace, 5 electric heat pump)
Heating equipment efficiency	93 AFUE furnace, 8.7 HSPF heat pump (n=60 total)	Not collected
Cooling equipment type	Majority central AC (n=82,80 central AC, 2 heat pump	Not collected
Cooling equipment efficiency	13.3 SEER	Not collected
Water heating equipment type	Mostly gas storage (n=71, 43 gas storage, 25 electric storage, 3 gas tankless)	Mostly gas storage (n=48, 26 gas storage, 18 electricity storage, 2 gas tankless, 1 electricity heat pump storage, 1 electricity - resistance tankless)
Water heating equipment capacity	55 gallons (n=62)	51 gallons (n=33)[1]
Water heating equipment efficiency	EF 0.82 (n=19)	EF 0.92 (n=1)

- **Successes:**
  - User manuals for mechanical systems provided (96%) in Phase I and 95% in Phase III.

3.2 Energy Intensity

The statewide energy analysis results in Figure 3.17 show an estimated decrease in EUI between Phase I and III of 2.82 kBtu/ft^2, which surpasses the 2.35 kBtu/ft^2 threshold for statistically significant savings. The observed data set (as gathered in the field) was compared against the same set of homes meeting prescriptive code requirements. In terms of overall energy consumption, homes in Pennsylvania appear to use less energy than would be expected relative to homes built to the current minimum state code requirements. However, the EUI increased between Phase I and Phase III. Table 3.21 compares the Phase I and Phase III results.

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

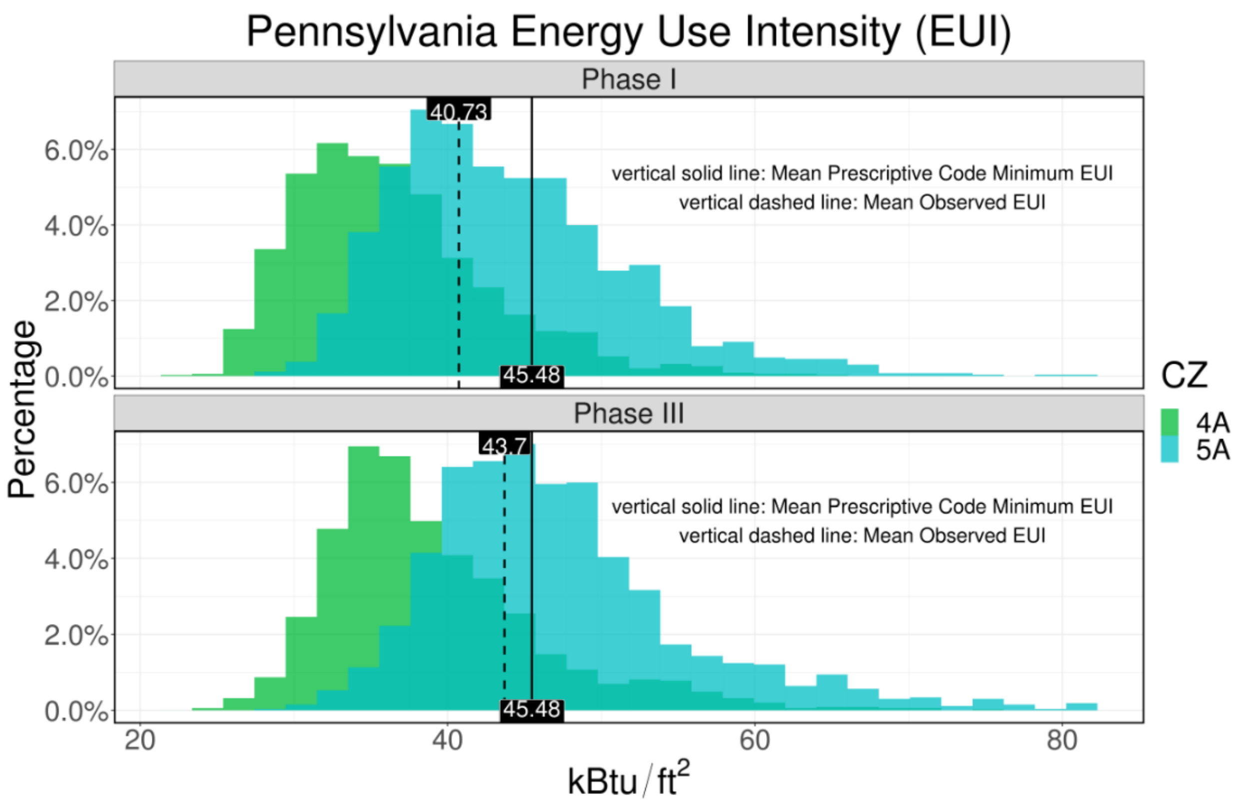

Figure 3.17. Comparison of Phase I and Phase III Statewide EUI for Pennsylvania

Table 3.21. Pennsylvania Statewide EUI in Phase I and Phase III

Prescriptive EUI[1]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
45.48	40.73	-10.4%	43.70	-3.9%	-7.3%

3.3 Savings Potential

Several key items in Phase I were previously identified as targets for improvements via education, training and compliance-improvement initiatives. Those with the greatest potential[2], shown below followed by the percent that met code, were further analyzed to estimate the associated savings potential for energy, cost and environmental impacts.

[1] Calculated based on the minimum prescriptive requirements of the state energy code.
[2] Defined here as those with less than 85% of observations meeting the prescriptive code requirement

Table 3.22. Comparison of Phase I and Phase III Compliance Rates by Measure in Pennsylvania

Measure	Phase I Compliance Rate	Phase III Compliance Rate	Phase III to Phase I Difference in Compliance Rate
Duct Tightness[1]	63%	48%	-15%
Exterior Wall Insulation	23%	40%	+17%
Ceiling Insulation	49%	16%	-33%
Lighting	62%	94%	+32%
Foundation Insulation			
Basement Wall Insulation	79%	35%	-44%
Floor Insulation	31%	14%	-17%
Slab-On-Grade Insulation	86%	100%	+14%

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

The results of the energy, cost, and environmental savings potential estimates are shown in Table 3.23. The results indicate that the Phase II education and training activities were successful in reducing the overall savings potential for all measures. In this case, improvement is measured by a reduction in measure-level savings potential between Phase I and Phase III.

Table 3.23. Comparison of Phase I and Phase III Estimated Annual Statewide Savings Potential

	Potential Total Energy Savings (MMBtu)		Potential Total Energy Cost Savings ($)		Potential Total State Emissions Reduction (MT CO2e)	
Measure	**Phase I**	**Phase III**	**Phase I**	**Phase III**	**Phase I**	**Phase III**
Duct Tightness	86,553	73,121	1,360,493	1,160,783	18,716	16,376
Exterior Wall Insulation	54,594	61,832	798,031	1,160,783	8,803	9,984
Ceiling Insulation	31,830	56,983	499,392	893,386	6,836	12,204
Lighting	4,868	45	365,254	41,178	15,476	2,031
Foundation Insulation	17,718	3,356	175,676	14,477	-1,306	-1,188
TOTAL	**195,563 MMBtu**	**195,337 MMBtu**	**$3,198,847**	**$3,013,496**	**48,526 MT CO2e**	**39,407 MT C02e**

On an individual measure basis, the Phase II education and training activities successfully reduced the savings potential for lighting, duct tightness, and foundation insulation. The measure-level energy cost savings for showed a reduction of 89% for lighting, 92% for foundation insulation, and 15% for duct tightness.

Two measures, ceiling insulation[2] and wall insulation, were not as successful, with savings increasing across all three metrics. However, overall energy cost measure-level savings showed a 5.8% reduction between Phase I and Phase III.[3] To reflect the longer-term cost savings potential of improved

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

[2] See previous discussion of ceiling insulation.

[3] Also note that while the EUI in Phase III was about 7.3% “worse” than in Phase I, the measure-level savings in Phase III are about 5.8% “better” than in Phase I. The reason that this can happen is that EUI and measure-level savings show two distinctly different facets of the housing stock in Pennsylvania.

compliance, annual savings were accumulated over 5, 10, and 30 years of new construction (Table 3.24). See Appendix D for additional details on electricity savings and natural gas savings per home associated with each measure; savings by individual foundation components; and total savings and emissions reductions accumulated over 5, 10, and 30 years of construction.

Table 3.24. Comparison of Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Potential Phase III vs. Phase I

	Potential Total Energy Cost Savings ($) 5 yr		Potential Total Energy Cost Savings ($) 10 yr		Potential Total Energy Cost Savings ($) 30 yr	
Measure	**Phase I**	**Phase III**	**Phase I**	**Phase III**	**Phase I**	**Phase III**
Duct Tightness	20,407,398	17,411,739	74,827,125	63,843,044	632,629,332	539,763,921
Exterior Wall Insulation	11,970,466	13,555,099	43,891,708	49,702,030	371,084,443	420,208,068
Ceiling Insulation	7,490,882	13,400,790	27,466,566	49,136,231	232,217,333	415,424,496
Lighting	5,478,811	617,663	20,088,973	2,264,764	169,843,137	21,099
Insulation Foundation Insulation	2,635,143	217,155	9,662,191	796,236	81,689,430	6,731,810
TOTAL	**$47,982,699**	**$45,202,447**	**$175,936,564**	**$165,742,304**	**$1,487,463,674**	**$1,382,149,394**

- EUI captures the energy impacts of the population of observations, including observations that fail to meet code, observations that meet code, and observations that exceed the performance of the code.
- The measure-level savings focuses solely on observations that fail to meet code.

Thus, if Phase III had fewer observations that exceeded the code requirement (or the magnitude of those observations was less compared to code), the EUI in Phase III would be worse than that in Phase I. And if the number and magnitude of observations that failed to meet code improved in Phase III, the measure-level savings in Phase III would be better than in Phase I. The two metrics are independent.

4.0 Conclusions

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. 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.

The Pennsylvania study had mixed results. There was a reduction in measure-level savings potential (an improvement), which is a successful outcome following the Phase II education and training efforts. However, there was also an increase in average estimated statewide energy use between Phase I and Phase III.

Based on the study's findings, the prototypical, newly constructed home in Pennsylvania consumes 3.9% less energy than a home exactly meeting the state code, however, energy usage increased by 7.3% from Phase I to Phase III as shown in Table 4.1.

Table 4.1. Average Modeled Energy Use Intensity in Pennsylvania (kBtu/ft^2-yr)

Prescriptive EUI[1]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
45.48	40.73	-10.4%	43.70	-3.9%	-7.3%

This results in over $185,000 in annual achieved savings, an improvement of 6% following the Phase II targeted education and training activities (Table 4.2)[2]. See Table 3.23 for potential total energy cost savings in each phase. The contributing factor to the reduction in measure-level savings potential was improvements in several key items: lighting, foundation insulation, and duct tightness, with lighting and foundation insulation having a particularly positive change. For ceiling insulation and wall insulation, the savings potential increased from Phase I to Phase III.

Table 4.2. Estimated Annual Statewide Cost Savings Potential

Measure	% Change
	Phase III vs. I
Duct Tightness	+15%
Exterior Wall Insulation	-13%
Ceiling Insulation	-79%
Lighting	+89%
Foundation Insulation	+92%
TOTAL	+6%

[1] Calculated based on the minimum prescriptive requirements of the state energy code.
[2] See Table 3.23 for potential total energy cost savings in each phase.

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

5.0 References

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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
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. Phase I 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 AREA, PERRY		1	0
	Peach Bottom township, York	0	1

PLACE, COUNTY	PLACE, COUNTY	SAMPLE	ACTUAL
PHILADELPHIA, PHILADELPHIA		5	4
PHOENIXVILLE BOROUGH, CHESTER		1	2
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

Table B.2. Phase III State Sampling Plan

PLACE, COUNTY	PLACE, COUNTY	SAMPLE	ACTUAL
ADAMS COUNTY, ADAMS		1	1
ARCHBALD BOROUGH, LACKAWANNA		1	.25
	Salem Township, Wayne	0	.75
BEDMINSTER TOWNSHIP, BUCKS		1	1
CALN TOWNSHIP, CHESTER		1	1
CHARLESTOWN TOWNSHIP, CHESTER		1	1

PLACE, COUNTY	PLACE, COUNTY	SAMPLE	ACTUAL
CONEWAGO TOWNSHIP, YORK		2	1
	York Township, York	0	.38
	Hanover Borough, York	0	.62
DOVER TOWNSHIP, YORK		1	.62
	Jackson Township, York	0	.38
EPHRATA TOWNSHIP, LANCASTER		1	.88
	West Early Township, Lancaster	0	.12
HAMPDEN TOWNSHIP, CUMBERLAND		1	1
JACKSON TOWNSHIP, YORK		1	1
LANSDALE BOROUGH, MONTGOMERY		1	1
	Cheltenham Township, Montgomery	0	.5
	Lancaster Township, Lancaster	0	.5
LEBANON COUNTY PART UNINCORPORATED AREA, LEBANON		2	2
LONDON GROVE TOWNSHIP, CHESTER		1	.25
	West Bradford Township, Chester	0	.5
	Valley Township, Chester	0	.5
LOWER HEIDELBERG TOWNSHIP, BERKS		1	.5
	Valley Township, Chester	0	.5
LOWER MACUNGIE TOWNSHIP, LEHIGH		3	3
LOWER PAXTON TOWNSHIP, DAUPHIN		1	1
MANCHESTER TOWNSHIP, YORK		1	1
MANHEIM TOWNSHIP, LANCASTER		1	1
MONROE TOWNSHIP, SNYDER		1	.62
	Selinsgrove Borough, Snyder	0	.38
MONTGOMERGY TOWNSHIP, MONTGOMERY		2	2
MOUNT JOY BOROUGH, LANCASTER		1	1
NEW HANOVER TOWNSHIP, MONTGOMERY		1	1
NEWTOWN TOWNSHIP, BUCKS		1	0
	Warwick Township, Bucks	0	1
NEWTOWN TOWNSHIP, DELAWARE		3	.5
	Middletown Township, Delaware	0	1.25
	Upper Pottsgrove, Montgomery	0	1.5
NORTH MIDDLETOWN TOWNSHIP, CUMBERLAND		1	.5
	Mechanicsburg Township, Cumberland	0	.5
PENN TOWNSHIP, LANCASTER		2	1.88
	Manheim Township, Lancaster	0	.12
PHILADELPHIA, PHILADELPHIA		6	6
PHOENIXVILLE BOROUGH, CHESTER		1	1
PLUMSTEAD TOWNSHIP, BUCKS		2	.5
	Hilltown Township, Bucks	0	.5
	Bethlehem Township, Northampton	0	1
SILVER SPRING TOWNSHIP, CUMBERLAND		4	4

PLACE, COUNTY	PLACE, COUNTY	SAMPLE	ACTUAL
SKIPPACK TOWNSHIP, MONTGOMERY		1	.75
	West Hempfield Township, Lancaster	0	.25
SPRINGFIELD TOWNSHIP, YORK		1	1
TOWAMENCIN TOWNSHIP,		1	0
MONTGOMERY	Upper Dublin Township, Montgomery	0	.12
	Cheltenham Township, Montgomery	0	.88
TREDYFFRIN TOWNSHIP, CHESTER		1	1
UPPER MACUNGIE TOWNSHIP, LEHIGH		5	5
UPPER MAKEFIELD TOWNSHIP, BUCKS		1	.38
	Warwick Township, Bucks	0	.12
	West Cocalico Township, Lancaster	0	.5
WARRINGTON TOWNSHIP, BUCKS		0	.5
	East Hempfield Township, Lancaster		
WARWICK TOWNSHIP, LANCASTER		1	1
WEST BRADFORD TOWNSHIP, CHESTER		1	1
WEST EARL TOWNSHIP, LANCASTER		1	1
WHITPAIN TOWNSHIP, MONTGOMERY		1	0
	Lower Salford Township, Montgomery	0	.5
WORCESTER TOWNSHIP, MONTGOMERY		1	1
TOTAL		63	63.88

B.2 Substitutions

In the Pennsylvania study, the following substitutions were made in Phase I:

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

In Phase III, 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 42 municipalities. Approximately 13 homes came from 17 unique replacement municipalities. The most common reasons for substitutions were that homes on the list were not at the right stage of construction, or the team was unable to gain access (usually for final phase diagnostic testing). As in Phase I, 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

Table C.1. Home Size

Home Statistics	Phase I	Phase III
Average Square Footage (ft^2)	2882	2645
Number of Stories	2.13	2.06
Number of Homes Visited	171	160

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

Conditioned Floor Area (ft^2)	< 1000	1000 to 1999	2000 to 2999	3000 to 3999	4000+
Percentage (Phase I)	1%	28%	36%	17%	18%
Percentage (Phase III)	2%	18%	49%	22%	9%

Table C.3. Number of Stories

No. of Stories	1	2	3	4+
Percentage (Phase I)	10%	68%	23%	0%
Percentage (Phase III)	7%	80%	13%	0%

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

C.1.1.2 Wall Profile

Table C.4. Wall Characteristics

Wall Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Framing Type			162	90
Frame Walls	100%	100%		
Framing Material			148	67
Wood	100%	100%		
Framing Depth			132	59
4 inch	56%	71%		
6 inch	44%	29%		
Type of Wall Insulation			62	62
Cavity Only	94%	98%		
Cavity + Continuous	5%	2%		
Continuous Only	2%	0%		

C.1.1.3 Foundation Profile

Table C.5. Foundation Characteristics

Foundation Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Foundation Type			171	134
Heated Basement	76%	66%		
Slab on Grade	21%	16%		
Crawlspace	0%	1%		
Basement Type			100	111
Conditioned	77%	80%		
Unconditioned	23%	20 %		

C.1.2 Compliance

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

C.1.2.1 Energy Code Used

Table C.6. Energy Code and Above Code Programs

Code or Above Code Program Used	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Energy Code Used			61	160
2009 IECC	98%	98%		
PA Alternative	2%	0%		
2006 IECC	0%	2%		
Was home participating in an above code program?			30	0
Yes	23%	NA		
No	77%	NA		
Which above code program?			6	0
Energy Star for Homes	33%	NA		
HERS	0%	NA		
Build Smart	67%	NA		
Not Observable	0%	NA		

C.1.3 Envelope

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

C.1.3.1 Insulation Labels

Table C.7. Thermal Envelope Characteristics

Thermal Envelope Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Was insulation labeled?			49	48
Yes	96%	42%		
No	4%	58%		
Did the attic hatch/door exhibit the correct insulation value?			61	22
Yes	69%	95%		
No	31%	5%		
Air Sealing in accordance with checklist[1]				
Thermal Envelope sealed?	74%	93%	27	15
Openings around doors and windows sealed?	95%	100%	40	35

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

Thermal Envelope Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Utility penetrations sealed?	88%	91%	52	11
Dropped ceilings sealed?	97%	0%	33	0
Knee walls sealed?	67%	67%	21	9
Garage walls and ceilings sealed?	82%	92%	55	13
Tubs and showers sealed?	57%	NA	28	0
Common walls sealed?	94%	NA	17	0
Attic access openings sealed?	3%	61%	67	31
Rim joists sealed?	56%	100%	56	3
Other sources of infiltration sealed?	94%	100%	16	3
IC-rated light fixtures sealed?	84%	NA	31	0

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

Table C.8. Duct & Piping System Characteristics

Duct & Piping System Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Duct location in conditioned space (average percentage)				
Supply	76%	73%	96	15
Return	78%	73%	95	8
Ducts entirely in conditioned space (number and percentage)				
Supply	34 duct systems (35%)	1 duct systems (7%)		
Return	46 duct systems (48%)	2 duct systems (25%)		
Ducts in unconditioned space insulation (R-value)				
Supply	5.9	5.4	26	10
Return	5.5	5.3	25	4
Ducts in attic insulation (R-value)				
Supply	NA7*	6.2	NA*	6
Return	NA*	10.0	NA*	1
Pipe insulation (R-value)			42	0
Average	R-3.2	NA		
Range	R-0 to R-5	N A		
Building cavities used as supply ducts	74%	100%	77	4
Air ducts sealed	85%	86%	53	7

Duct & Piping System Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Air handlers sealed	93%	34%	58	34
Filter boxes sealed	79%	34%	85	38

*Ducts in attic insulation data not on data collection for PA in Phase I

C.1.5 HVAC Equipment

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

C.1.5.1 Heating

Table C.9. Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			116	54
Gas	95%	91%		
Electricity	5%	9%		
System Type			116	56
Furnace	95%	90%		
Heat Pump	5%	10%		
Average System Capacity			46	6
Furnace	70,065 Btu/hr	91,000 Btu/hr		
Heat Pump	NA*	NA*		
Average System Efficiency			60	7
Furnace	93 AFUE	92 AFUE		
Heat Pump	9 HSPF	9 HSPF		

*no data collected

C.1.5.2 Cooling

Table C.10. Cooling Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			82	15
Central AC	98%	73%		
Heat Pump	2%	27%		
Average System Capacity			23	3
Central AC	33,000 Btu/hr	28,400 Btu/hr		
Heat Pump	NA*	42,000 Btu/hr		
Average System Efficiency	13.3 SEER	13 SEER	59	4

C.1.5.3 Water Heating

Table C.11. Water Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			107	48
Gas	73%	58%		
Electricity	27%	42%		
System Type			71	48
Storage	96%	94%		
Tankless	4%	6%		
Average System Capacity	55 gal	51 gal	62	33
Average System Efficiency			19	1
Electric Storage (non-heat pump)	EF 0.91	EF 0.91	11	1
Electric Storage (heat pump)	No observations	No observations	0	0
Electric Tankless	No observations	No observations	0	0
Gas Storage	EF 0.66	No observations	7	0
Gas Tankless	EF 0.94	No observations	1	0

Table C.12. Water Heating System Storage Capacity Distribution

Capacity	< 50 gal	50-59 gal	60-69 gal	70-79 gal	80-89 gal	90+ gal
Phase I Percentage	0%	76%	13%	2%	10%	0%
Phase III Percentage	0%	94%	6%	0%	0%	0%

C.1.5.4 Ventilation

Table C.13. Ventilation Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			7	59
Exhaust Only	71%	100%		
Standalone ERV/HRV	29%	0%		
Exhaust Fan Type			5	59
Dedicated Exhaust	0%	25%		
Bathroom Fan	100%	75%		

C.1.5.5 Other

Table C.14. Other Mechanical System Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Mechanical Manuals Provided	96%	95%	70	37
Programmable Thermostat Installed	99%	75%	67	4

Appendix D

Energy Savings

Appendix D

Energy Savings

D.1 Measure-Level Savings

This appendix contains detailed measure-level annual savings results for both Phase I (Table D.1) and Phase III (Table D.3) for Pennsylvania, with additional foundation insulation details shown in Table D.2 and Table D.4. Also included are multi-year (5-year, 10-year, and 30-year) aggregations of the annual results in Table D.5, Table D.6, and Table D.7. The multi-year savings reflect the same reductions and increases as the annual savings and are simply the annual savings multiplied by 15, 55, and 465 for 5-year, 10-year, and 30-year savings, respectively. For analytical details refer to Section 2.3.3 (Savings Analysis) or the methodology report (DOE 2018).

Table D.1. Phase I Statewide Annual Measure-Level Savings Potential for 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 Tightness	4A	215	46	5,359	7,040	37,728	594,504	8,232
	5A	206	45	5,233	9,331	48,828	766,056	10,486
	State Total	**210**	**46**	**5,287**	**16,371**	**86,553**	**1,360,493**	**18,716**
Exterior Wall Insulation	4A	16	5	532	7,040	3,745	55,233	628
	5A	159	49	5,449	9,331	50,849	742,797	8,174
	State Total	**98**	**30**	**3,335**	**16,371**	**54,594**	**798,031**	**8,803**
Ceiling Insulation ***	4A	76	15	1,766	7,040	12,432	199,719	2,904
	5A	77	18	2,076	9,331	19,390	299,567	3,932
	State Total	**77**	**17**	**1,944**	**16,371**	**31,830**	**499,392**	**6,836**
Foundation Insulation*	4A	-31	16	1,482	6,312	6,573	66,149	-436
	5A	-61	22	2,016	8,366	11,138	109,462	-869
	State Total	**-48**	**20**	**1,788**	**14,677**	**17,718**	**175,676**	**-1,306**
Lighting*	4A	179	-3	312	7,040	2,193	158,333	6,662
	5A	179	-3	287	9,331	2,676	206,930	8,815
	State Total	**179**	**-3**	**297**	**16,371**	**4,868**	**365,254**	**15,476**
TOTAL		**514**	**109**	**12,651**	**Varies**	**195,563**	**3,198,847**	**48,526**

* 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 **Error! Reference source not found.** for annual measure-level savings results by foundation type. ** Ceiling insulation was not marked as a focal point for education for Phase II due to Ceiling R-value compliance not meeting the 15% non-compliance cutoff for inclusion in the Phase I measure-level savings analysis. By the time the PA Phase III analysis was done, DOE had changed to using ceiling U-factors rather than R-values for the cutoff. Had that been the case prior to the Phase I analysis, ceiling insulation would have been a focal point in Phase II. To provide a more complete comparison between Phase I and Phase III, DOE included ceiling insulation in the above table as well as in a revised Phase I measure-level savings estimate.

Table D.2. Phase I Statewide Annual Measure-Level Savings Potential by Foundation Type

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	-278
	5A	-11	17	1,708	6,113	10,444	113,480	-274
	State Total	**-12**	**16**	**1,573**	**10,726**	**16,870**	**181,101**	**-552**
Floor Insulation	4A	-18	2	91	1,699	154	-1,400	-158
	5A	-50	5	308	2,252	693	-4,019	-595
	State Total	**-36**	**3**	**215**	**3,952**	**849**	**-5,425**	**-754**
Total		**-48**	**20**	**1,788**	**14,677**	**17,718**	**175,676**	**-1,306**

*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 D.3. Phase III Statewide Annual Measure-Level Savings Potential 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 Tightness	4A	188	39	4,539	7,040	31,950	508,393	7,216
	5A	180	38	4,413	9,331	41,171	652,389	9,162
	State Total	**184**	**38**	**4,467**	**16,371**	**73,121**	**1,160,783**	**16,376**
Exterior Wall Insulation	4A	21	6	674	7,040	4,741	69,913	795
	5A	178	55	6,119	9,331	57,091	833,760	9,164
	State Total	**111**	**34**	**3,787**	**16,371**	**61,832**	**903,673**	**9,984**
Ceiling Insulation	4A	135	27	3,161	7,040	22,249	357,183	5,182
	5A	138	33	3,723	9,331	34,733	536,203	7,021
	State Total	**137**	**30**	**3,482**	**16,371**	**56,983**	**893,386**	**12,204**
Lighting	4A	24	0	41	7,040	288	20,818	876
	5A	23	-1	-26	9,331	-243	20,360	1,155
	State Total	23	-1	3	16,371	45	41,178	2,031
Foundation Insulation	4A	-19	3	258	6,312	999	6,212	-258
	5A	-70	9	638	8,366	2,357	8,265	-928
	State Total	**-48**	**6**	**475**	**Varies**	**3,356**	**14,477**	**-1,188**
TOTAL		**406**	**108**	**12,213**	**Varies**	**195,337**	**3,013,496**	**39,407**

Table D.4. Phase III Statewide Annual Measure-Level Savings Potential by Foundation Type

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	-6	2	193	4,612	888	7,363	-137
	5A	-5	3	238	6,113	1,457	13,242	-167
	State Total	**-6**	**2**	**219**	**10,726**	**2,345**	**20,605**	**-305**
Floor Insulation	4A	-14	1	65	1,699	111	-1,151	-121
	5A	-65	6	400	2,252	900	-4,977	-761
	State Total	**-43**	**4**	**256**	**3,952**	**1,011**	**-6,128**	**-883**
Total		**-48**	**6**	**475**	**14,677**	**3,356**	**14,477**	**-1,188**

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

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	1,298,291	4,760,401	40,247,030	$20,407,398	$74,827,125	$632,629,332	280,742	1,029,389	8,703,016
Exterior Wall Insulation	818,909	3,002,666	25,386,177	11,970,466	43,891,708	371,084,443	132,038	484,140	4,093,183
Ceiling Insulation	477,451	1,750,653	14,800,979	7,490,882	27,466,566	232,217,333	102,544	375,996	3,178,873
Lighting	79,019	267,736	2,263,589	5,478,811	20,088,973	169,843,137	232,143	851,190	7,196,423
Foundation Insulation	265,776	974,514	8,239,069	2,635,143	9,662,191	81,689,430	-19,583	-71,804	-607,066
TOTAL	**2,933,447**	**10,755,971**	**90,936,844**	**47,982,699**	**175,936,564**	**1,487,463,674**	**727,885**	**2,668,911**	**22,564,429**

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

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	1,096,820	4,021,674	34,001,422	17,411,739	63,843,044	539,763,921	245,646	900,703	7,615,034
Exterior Wall Insulation	927,479	3,400,755	28,751,836	13,555,099	49,702,030	420,208,068	149,754	549,098	4,642,375
Ceiling Insulation	854,738	3,134,039	26,496,875	13,400,790	49,136,231	415,424,496	183,062	671,229	5,674,932
Lighting	681	2,496	21,099	617,663	2,264,764	21,099	30,459	111,683	944,229
Foundation Insulation	50,343	184,591	1,560,631	217,155	796,236	6,731,810	-17,818	-65,331	-552,345
TOTAL	**2,930,060**	**10,743,554**	**90,831,862**	**$45,202,447**	**$165,742,304**	**$1,382,149,394**	**591,104**	**2,167,381**	**18,324,225**

Table D.7. Difference between Five-years, Ten-years, and Thirty-years Cumulative Statewide Savings Potential Phase III vs. Phase I

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Duct Tightness	201,471	738,728	6,245,609	2,995,658	10,984,081	92,865,410	35,096	128,686	1,087,982
Exterior Wall Insulation	-108,570	-398,089	-3,365,659	-1,584,633	-5,810,321	-49,123,625	-17,716	-64,958	-549,192
Ceiling Insulation	-377,287	-1,383,386	-11,695,896	-5,909,909	-21,669,665	-183,207,164	-80,518	-295,233	-2,496,059
Lighting	72,338	265,241	2,242,490	4,861,148	17,824,209	169,822,038	201,684	739,507	6,252,194
Foundation Insulation	215.433	890.023	6,678,438	2,417,988	8,865,955	74,957,620	-1,765	-6,472	-54,721
TOTAL	3,387	12,417	104,982	2,780,253	10,194,259	105,314,280	136,781	501,529	4,240,204

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