PNNL-31137

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Texas Residential Energy Code Field Study: Final Report

September 2022

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

U.S. DEPARTMENT OF ENERGY

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

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.

(8/2010)

PNNL-31137

Texas Residential Energy Code Field Study: Final Report

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

September 2022

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

Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

A research project in the state of Texas 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 Texas 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 October 2015. During this period, research teams visited 133 homes in 30 counties in and around Houston during various stages of construction, resulting in a substantial data set based on observations made directly in the field. Stakeholders in the state agreed that these 30 counties represented levels of energy codes and enforcement seen across the state. At the project team's request, the analytical results were calculated in two ways: Climate Zone (CZ) 2A results only and results extrapolated statewide from the CZ2A data. For the statewide results, the CZ2A data were used as observed values in all of the climate zones and analytical results were extrapolated statewide. This extrapolation was repeated in Phase III. See Section 2.4.1 for additional details. The results in the main body of this report are presented for the CZ2A data. Statewide results are presented in Appendix E. Analysis of the Phase I data led to a better understanding of the energy features typically present in Texas homes, and indicated over $4.8 million in potential annual savings to homeowners that could result from increased code compliance (Table ES.2).

Starting in December 2015 and continuing through March 2018, members of the Texas field study team conducted targeted education and training activities (Phase II). Those activities included classroom and webinar training, factsheets, and checklists. 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 136 homes across the state between April 2018 and September 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 the National Association of State Energy Officials (NASEO) with support from the South-central Partnership for Energy Efficiency as a Resource (SPEER) and Cadmus. The team applied a methodology prescribed by the U.S. Department of Energy (DOE), which was based on collecting information for the energy code-required building components with the largest direct impact on energy consumption. These *key items* are a focal point of the study, and in turn drive the analysis and savings estimates[1]. As part of both the pre- and post-studies, the project team implemented customized

[1] See Section 2.1

sampling plans representative of new construction within the state, which were originally developed by Pacific Northwest National Laboratory (PNNL) and then vetted with stakeholders.

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.

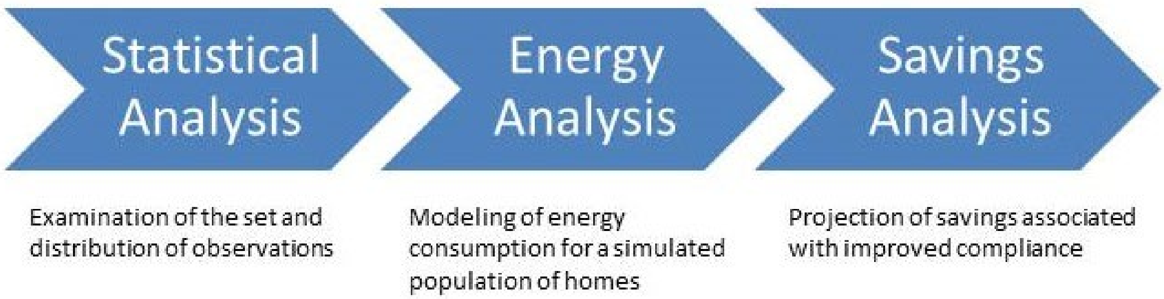

Figure ES.1. Stages of Analysis Applied in the Study

During the Phase I data collection period, the state energy code was the 2009 International Residential Code (IRC) with no amendments. The state energy code was updated to the 2015 IRC prior to Phase III data collection. Therefore, Phase I data collection occurred with homes permitted under the 2009 IRC, while Phase III data collection occurred with homes permitted under the 2015 IRC. All of the results in this report are based on the 2015 International Energy Conservation Code (IECC), which is equivalent to the 2015 IRC, as that is the code that states would need to comply with in the future, and that was the focus of training in the state, and so a direct comparison between Phase I and Phase III savings potential can be made.

Success for the study is characterized by the following between Phase I and Phase III: 1) a measurable decrease in estimated statewide energy use [a change in energy use intensity (EUI) of at least 1.25 kBtu/ft^2] and 2) a reduction in measure-level savings potential. To estimate average statewide energy consumption, field data was analyzed to calculate average statewide energy use as characterized by EUI. Field observations from Phase I and Phase III were analyzed independently and compared to a scenario based on the state energy code's minimum prescriptive requirements (the 2015 IECC). 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 1.9 percent more energy than would be expected relative to homes built to the minimum prescriptive requirements of the 2015 IECC. This percentage improved to 6.4 percent less energy in Phase III, representing a change in EUI of approximately 8.1 percent (1.83 kBtu/ft^2) between Phases I and III.

Table ES.1. Average Modeled Energy Use Intensity in Texas CZ2A (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)
22.15	22.57	+1.9%	20.74	-6.4%	-8.1%

Next, the field data was assessed from the perspective of individual energy efficiency measures, or the key items with the greatest potential for savings in the state, as presented in Table ES.2. These figures represent the potential annual savings associated with each observable measure compared to a counterfactual scenario where all observations meet the prescriptive code requirement. The statistical trends were then extrapolated based on projected new construction across the state. These items, as identified in the Phase I baseline field study, were targeted as a focal point for Phase II education and 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 Texas CZ2A Cost Savings Potential

	Total Energy Cost Savings Potential ($)		$ Change	% Change
Measure	Phase I	Phase III	Phase III vs. I	Phase III vs. I
Envelope Air Tightness	654,623	170,471	-484,152	-73.9%
Exterior Wall Insulation	511,748	359,086	-152,662	-29.8%
Duct Tightness	1,914,867	170,171	-1,744,696	-91.1%
Lighting	1,550,412	4,050	-1,546,362	-99.7%
Ceiling Insulation	216,147	540,180	+324,033	+149.9%
TOTAL	**$4,847,797**	**$1,243,958**	**-$3,603,839**	**-74.3%**

Overall, there was a reduction in savings potential between Phase I and Phase III. This is an improvement of 74 percent and over $3.6 million in annual cost savings achieved by Phase II targeted education and training activities. Despite the positive impact of the project, a savings potential of over $1.2 million still remains that can be further reduced through targeted education and training.

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 Texas. 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. See Appendix E for EUI and savings potential results based on a statewide extrapolation of CZ2A results. 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.

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

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

- Chris Wagner, *National Association of State Energy Officials (NASEO)*
- Todd Sims, *NASEO*
- Ed Carley, *NASEO*
- Rodney Sobin, *NASEO*
- Richard Morgan, *South-central Partnership for Energy Efficiency as a Resource (SPEER)*
- Chris Herbert, *SPEER*
- Eric Makela, *Cadmus Group (Cadmus)*
- Jolyn Green, *Cadmus*
- Jerica Stacey, *Cadmus*
- Allen Lee, *Cadmus*

NASEO

The National Association of State Energy Officials is a national non-profit association for the governor-designated energy officials from each of the 56 states and territories. Formed by the states in 1986, NASEO facilitates peer learning among state energy officials, serves as a resource for and about state energy offices, and advocates the interests of the state energy offices to Congress and federal agencies. For more information on NASEO, visit http://www.naseo.org.

SPEER

The South-central Partnership for Energy Efficiency as a Resource is a regional energy efficiency organization that aims to accelerate the adoption of advanced building systems and energy efficient products and services in Texas and Oklahoma. For more information, see https://eepartnership.org.

Cadmus

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

Acronyms and Abbreviations

AC	air conditioning
ACH	air changes per hour
AFUE	annual fuel utilization efficiency
AHU	air handling unit
BOAT	Building Officials Association of Texas
Btu	British thermal unit
cfm	cubic feet per minute
CFA	conditioned floor area
CO2e	carbon dioxide equivalent
CZ	climate zone
DOE	U.S. Department of Energy
EF	energy factor
ESL	Energy Systems Laboratory of Texas A&M University
EUI	energy use intensity
EUMMOT	Electric Utility Marketing Managers of Texas
FOA	funding opportunity announcement
GHBA	Greater Houston Builders Association
HSPF	heating season performance factor
ICC	International Code Council
IECC	International Energy Conservation Code
IIQ	insulation installation quality
IRC	International Residential Code
kBtu	thousand British thermal units
MMBtu	million British thermal units
MT	metric ton
NA	not applicable
NASEO	National Association of State Energy Officials
PNNL	Pacific Northwest National Laboratory
ROI	return on investment
SECO	Texas State Energy Conservation Office
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SPEER	South-central Partnership for Energy Efficiency as a Resource
TAB	Texas Association of Builders
TECCC	Texas Energy Code Compliance Collaborative
TX	Texas

Contents

Figures

Tables

1.0 Introduction

A three-phase research project in the state of Texas 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 October 2015. During this period, research teams visited 133 homes in 30 counties in and around Houston during various stages of construction, resulting in a substantial data set based on observations made directly in the field. Stakeholders in the state agreed that these 30 counties represented levels of energy codes and enforcement seen across the state. At the project team's request, the analytical results were calculated in two ways: Climate Zone (CZ) 2A results only and results extrapolated statewide from the CZ2A data. For the statewide results, the CZ2A data were used as observed values in all of the climate zones and analytical results were extrapolated statewide. This extrapolation was repeated in Phase III. See Section 2.4.1 for additional details.

The results in the main body of this report are presented for the CZ2A data. Statewide results are presented in Appendix E. Analysis of the Phase I data led to a better understanding of the energy features typically present in Texas homes, and indicated nearly $5 million in potential annual savings to homeowners in the state that could result from increased code compliance.

Starting in December 2015 and continuing through March 2018, members of the Texas field study team conducted targeted education and training activities (Phase II). Those activities included classroom and webinar training, factsheets, and checklists. 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 136 homes across the state between April 2018 and September 2018. The results of this effort are presented in Section 3.0.

At the time of Phase I of the study, Texas had the 2009 International Residential Code (IRC) with no amendments. Following Phase I data collection, the state proceeded in adopting an updated energy code, known as the 2015 Texas Energy Code.[1] Therefore, Phase I data collection occurred with homes permitted under the 2009 IRC, while Phase III data collection occurred with homes permitted under the 2015 IRC. All of the results in this report, including savings potential, are based on the 2015 International Energy Conservation Code (IECC), which is equivalent to the 2015 IRC, as that was the code that homes would need to comply with in the future, and so a direct comparison between Phase I and

[1] The 2015 Texas Energy Code is based on the 2015 International Residential Code with state amendments to modify the Energy Rating Index values and is available at http://seco.cpa.state.tx.us/tbec/singlefam.php.

Phase III can be made. The study methodology, data analysis and resulting findings are presented throughout this report.

1.1 Background

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

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

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

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

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

1.2 Project Team

The Texas project was led by the National Association of State Energy Officials (NASEO), with support from the South-central Partnership for Energy Efficiency as a Resource (SPEER), and field data collected by Cadmus. The Pacific Northwest National Laboratory (PNNL) defined the methodology, conducted data analysis, and provided technical assistance to the project team. Funding and overall program direction was provided by the DOE Building Energy Codes Program as part of a broader initiative being conducted across several U.S. states. More information on the organizations comprising the project team is included in the Acknowledgements section of this report.

1.3 Stakeholder Interests

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

- Building officials

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

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

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

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

2.0 Methodology

2.1 Overview

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

Highlights of the methodology:

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

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

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

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

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

Success for the study is characterized by the following between Phase I and Phase III: 1) a measurable decrease in estimated statewide energy use [a change in energy use intensity (EUI) of at least 1.25 kBtu/ft^2} and 2) a reduction in measure-level savings potential.

The following sections describe how the methodology was implemented as part of the Texas 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

Given both the large geographic size and population of Texas, the project team decided to limit data collection to an area comprising 30 counties in south central and southeast Texas anchored on Houston (all climate zone 2). It includes dense metropolitan areas, small- to mid-size cities and towns and unincorporated areas of counties and has a population of approximately 7 million, about 25% of the state population.

An initial sample plan for the area was first developed by PNNL, and then vetted by stakeholders within the state. For purposes of the study, stakeholders agreed that this area could be used to represent the entire state as it includes a broad range of the energy codes in use and levels of enforcement seen across the state. The samples were apportioned to individual jurisdictions in proportion to their average level of construction over the past three years compared to the overall construction activity in the 30 counties[4]. This approach is 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 for the 30-county area). The sample taken in the 30-county area was also adjusted so that the ratio of urban to rural areas was similar to the overall state ratio. See Section 2.4.1, Applicability of Results, for additional discussion of how the data collected in CZ2A was applied to the entire state.

Special considerations were discussed by stakeholders at the 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 plans shown in Appendix B.

2.2.2 Data Collection

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

[3] Available at https://www.energycodes.gov/residential-energy-code-field-studies.
[4] Available at http://censtats.census.gov/ (select the "Building Permits" data)

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] in Phase I and the 2015 IECC[6] in Phase III. The final data collection form is available in spreadsheet format on the DOE Building Energy Codes Program website.[7] The form included all energy code requirements (i.e., not just the eight key items), as well as additional items required under the prescribed methodology. For example, the field teams were required to conduct a blower door test and duct tightness test on every home where such tests could be conducted, using RESNET[8] protocols.

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

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

2.2.2.2 Data Management and Availability

Once each data collection effort was complete, the project team conducted a thorough quality assurance review. This included an independent check of raw data compared to the information provided to PNNL for analysis, and helped to ensure completeness, accuracy and consistency across the inputs. Prior to submitting the data to PNNL, the team also removed all personally identifiable information, such as project site locations and contact information. The final dataset for each Phase is available in spreadsheet format on the DOE Building Energy Codes Program website.[9]

---

[5] Several questions were removed as they were not applicable to Texas: basements and crawlspaces, slab insulation, and snow and ice melting systems.
[6] The Phase III data was collected with an un-edited version of the 2015 IECC data collection form and thus had questions related to the features discussed in the previous footnote.
[7] Available at https://www.energycodes.gov/residential-energy-code-field-studies based on the forms typically used by the RES*check* compliance software.
[8] See https://www.resnet.us/wp-content/RESNET-Mortgage-Industry-National-HERS-Standards_3-8-17.pdf.
[9] Available at https://www.energycodes.gov/residential-energy-code-field-studies.

2.3 Data Analysis

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

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

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

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

2.3.1 Statistical Analysis

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

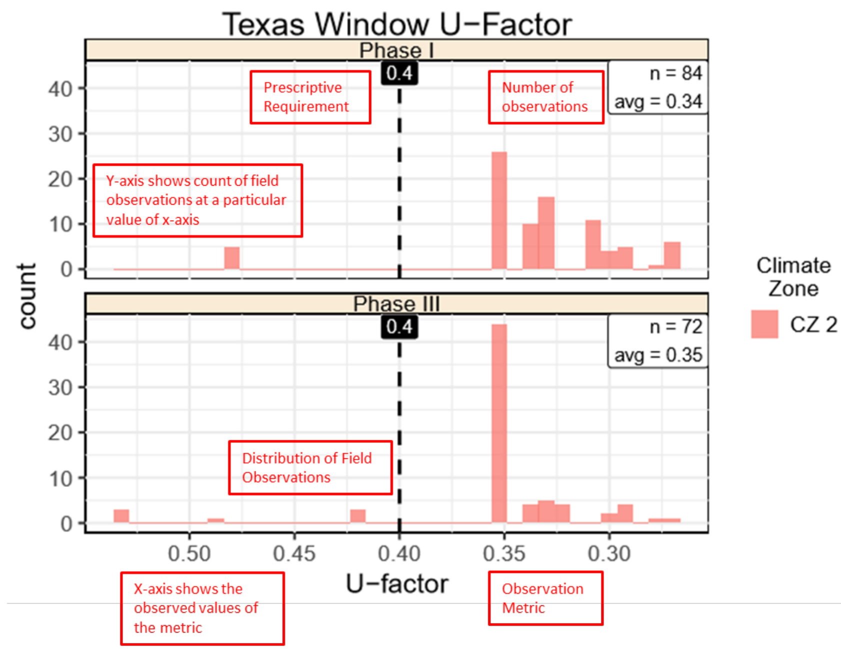

Figure 2.1. Sample Graph

Each graph is set up in a similar fashion, identifying the *state*, *climate zone*, and specific item being analyzed. The total *sample size* (n) is displayed in the top left or right corner of the graph, along with the distribution *average*. The *metric* associated with the item is measured along the horizontal axis (e.g., window U-factor is measured in Btu/ft^2-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 CZ2 is 0.4)—values to the right-hand side of this line represent observations which are *better than code*. Values to the left-hand side represent areas for improvement.

2.3.2 Energy Analysis

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

Energy simulation was then conducted using the EnergyPlus™ software.[10] Each of the 1,500 models was run multiple times, to represent each combination of heating systems and foundation types commonly found in the state. This resulted in upwards of 30,000 simulation runs for each climate zone within the state. An EUI was calculated for each simulation run and these results were then weighted by the frequency with which the heating system/foundation type combinations were observed in the field data.

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

Average EUI was calculated based on regulated end uses (heating, cooling, lighting and domestic hot water) for two sets of homes—one *as-built* set based on the data collected in the field, and a second *code-minimum* set (i.e., exactly meeting minimum code requirements). Comparing these values shows whether the population of newly constructed homes in the state is using more or less energy than would be expected based on minimum code requirements. In the energy analysis, the presence of both above code and below code items is included and therefore reflected in the statewide EUI.

Further specifics of the energy analysis are available in a supplemental methodology report (DOE 2018).[11]

2.3.3 Savings Analysis

To begin the third stage, each of the key items was examined individually to determine which had a significant number of observed values that did not meet the associated code requirement[12]. For these items, additional models were created to assess the savings potential, comparing what was observed in the field to a scenario of full compliance (i.e., where all worse-than-code observations for a particular item exactly met the corresponding code requirement).[13] The worse-than-code observations for the key item under consideration are used to create a second set of models (*as built*) that can be compared to the baseline (*full compliance*) models. All other components were maintained at the corresponding prescriptive code value, allowing for the savings potential associated with a key item to be evaluated in isolation.

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

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

Another aspect of savings potential that is not included is the presence of better-than-code items. While it is indeed possible that one better-than-code component may offset the energy lost due to another worse-than-code component, the collected data does not allow for the assessment of paired observations for a

---

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

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

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

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.

An 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 leakage 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 are statistically significant only in the geographical region that was sampled; the 30-county area comprising the sample. The results were also extrapolated to the entire state at the project team's request (see Appendix E for the extrapolated results). In absence of additional data, data collected in CZ2A were analyzed in CZ3A, CZ3B, and CZ4B assuming that construction would remain similar (i.e., observed values from CZ2A were used as observed values in the other climate zones as well). Specifically, the random sampling process was applied to the set of observations in each CZ separately, followed by simulation runs. The state EUI results were derived by aggregating the results of the multiple climate zones-moisture regimes weighted with the CZ construction fractions provided by the project team (i.e., CZ2A:55%, CZ3A: 33%, CZ3B: 11% and CZ4B: 1%).

Other results, such as analysis based on climate zone level, reporting of non-key items (e.g., gas furnace efficiency), or further stratifications of the public data set are included and available but should not be considered statistically representative.

2.4.2 Definition and Determination of Compliance

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

2.4.3 Sampling Substitutions

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

2.4.4 Site Access

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

2.4.5 Analysis Methods

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

2.4.6 Presence of Tradeoffs

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

2.5 Phase II Targeted Education and Training

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

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

For any given state, a variety of activities was used, ranging from more traditional activities such as classroom-based training, to more advanced approaches, such as web-based and onsite education, as well as circuit rider[14] 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 Texas, specific Phase II activities included:

- Outreach materials: Handouts, social media messaging and factsheets for each measure to drive target audiences to training and webinars.
- Training: There were 70 field study trainings and webinars with over 1,850 attendees, including inspectors, builders, contractors, plan reviewers, city leaders, and designers. International Code Council CEUs were made available for each event. Field sessions ranged from classroom settings to early morning workshops with insulation contractors at warehouses. The project team recommends providing a point of contact participants can ask questions of or request more training.
- Other: Additional resources that were developed to support the project include: fact sheets and inspection checklists. Fact sheet[15] topics include lighting requirements, HVAC system duct sealing and testing, envelope sealing and air tightness, insulation R-value and installation quality, and HVAC sizing. A residential inspection high impact checklist and a residential plan review high impact checklist were also created.

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. The following quantities that were derived from Phase I data and analysis were held constant between Phase I and Phase III:

[14] 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).
[15] The fact sheets and checklists are available at https://eepartnership.org/program-areas/energy-codes-2/energy-codes/2015-energy-code-adoption-toolkit/code-adoption-tools/training-and-resources/.

- Annual number of permits estimated for the state and the split of permits between climate zones in multi-climate zone states
- Distribution of heating system types in the state
- Distribution of foundation types in the state
- Number of observations of key items per climate zone in multi-climate zone states used in the Monte Carlo simulations
- 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. Texas has multiple climate zones, but samples were only taken from CZ2A. The data taken from CZ2A was treated as a representative data set of the state and was used to generate models for the other three climate zones/moisture regimes. (See Section 2.4.1, Applicability of Results for more information on how the CZ2 observations were used in the statewide analysis.)

3.0 State Results

3.1 Field Observations

3.1.1 Key Items

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

The following key items were found applicable within the state:

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

The predominant foundation type observed was slab-on-grade. Since Texas has no insulation requirement for slabs in CZ2 under the 2015 Texas Energy Code, and because the project team specifically requested removal of the foundation insulation questions from the data collection form, foundation insulation is not included in this section.

All of the results in this section are based on comparison to the 2015 IECC.

3.1.1.1 Envelope Tightness

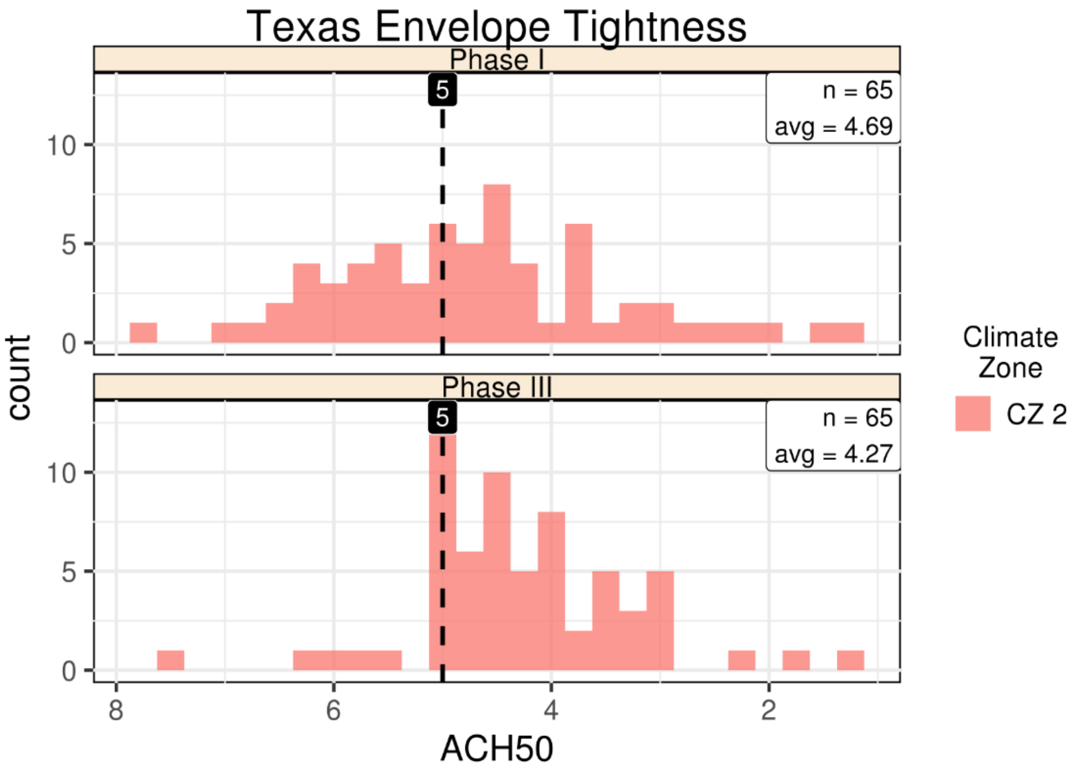

Figure 3.1. Comparison of Phase I and Phase III Envelope Tightness for Texas CZ2A

Table 3.1. Texas CZ2A Envelope Tightness in Phase I and Phase III

Envelope Tightness (ACH50)	Phase I	Phase III
Requirement	5.0	5.0
Observations		
Number	65	65
Range	7.9 to 1.2	7.6 to 1.3
Average	4.7	4.3
Compliance Rate	39 of 65 (60%)	60 of 65 (92%)

- **Interpretations**
  - In Phase I, reductions in envelope air tightness represented an area for improvement in the state and was a focus of Phase II education and training activities.
  - There was significant improvement (from 60% compliance to 92% compliance) after the Phase II activities.

3.1.1.2 Window SHGC

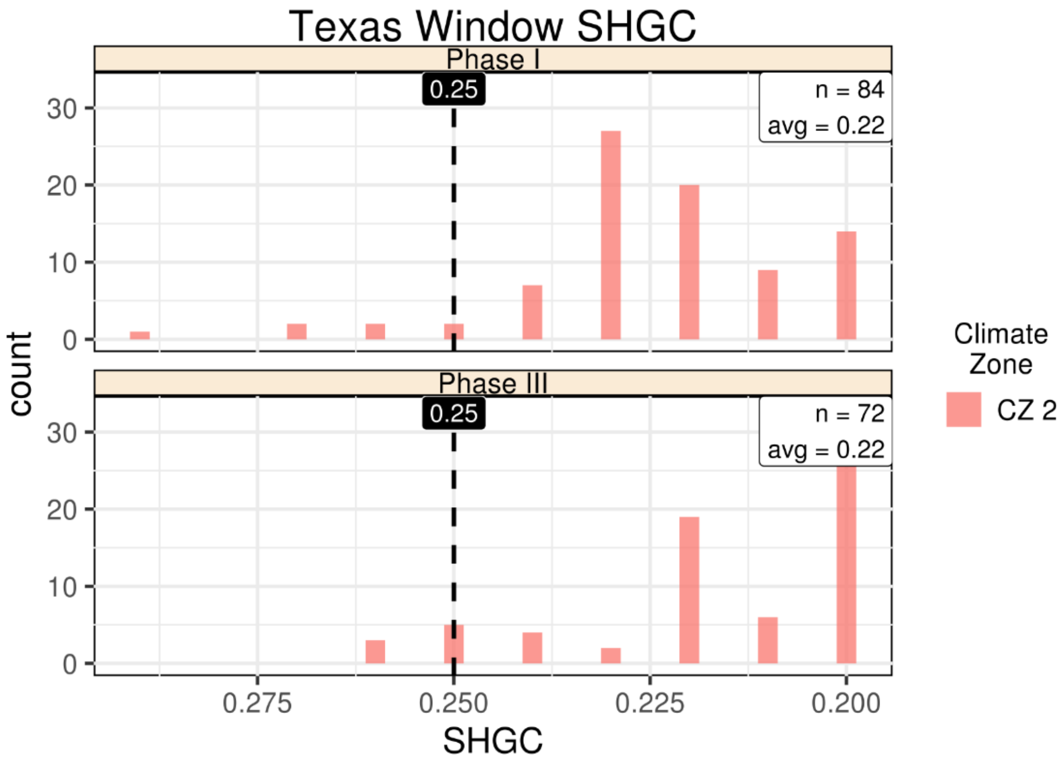

Figure 3.2. Comparison of Phase I and Phase III Window SHGC for Texas CZ2A

Table 3.2. Texas CZ2A Window SHGC in Phase I and Phase III

Window SHGC	Phase I	Phase III
Requirement	0.25	0.25
Observations		
Number	84	72
Range	0.29 to 0.20	0.26 to 0.2
Average	0.22	0.22
Compliance Rate	79 of 84 (94%)	69 of 72 (96%)

- **Interpretations:**
  - Compliance was comparable in both Phase I (94%) and Phase III (96%), with a modest improvement in Phase III.

3.1.1.3 Window U-Factor

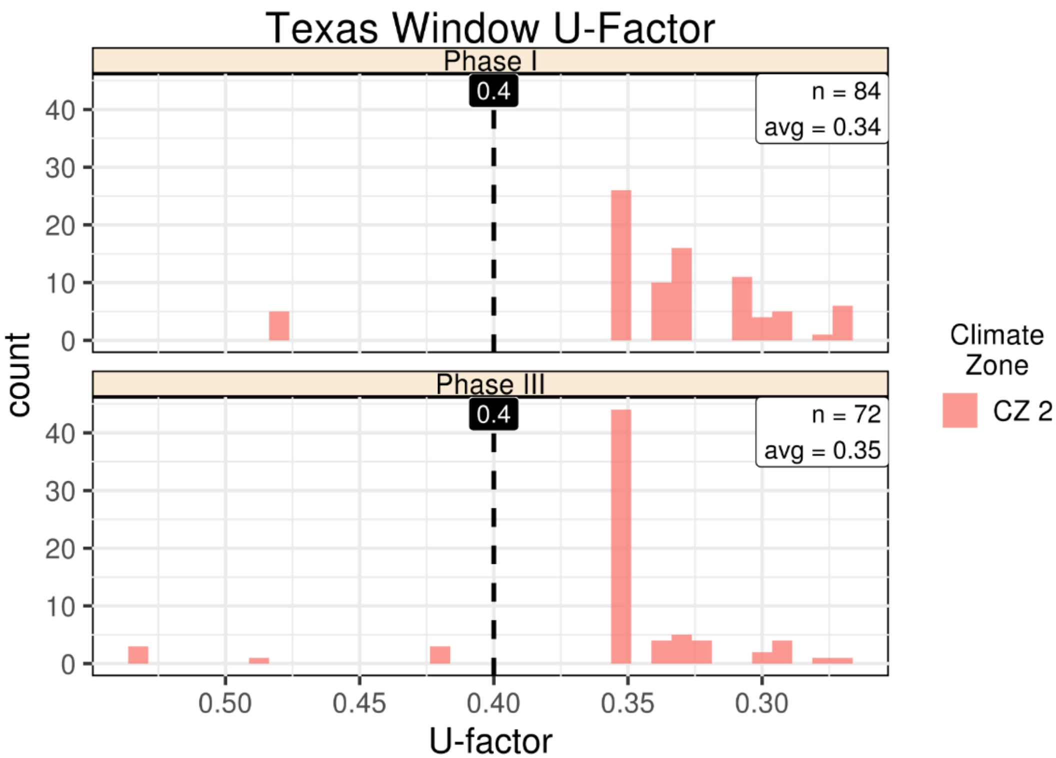

Figure 3.3. Comparison of Phase I and Phase III Window U-Factors for Texas CZ2A

Table 3.3. Texas CZ2A Window U-Factors in Phase I and Phase III

Window U		Phase I	Phase III
Requirement		0.40	0.40
Observations			
	Number	84	72
	Range	0.48 to 0.27	0.53 to 0.27
	Average	0.34	0.35
	Compliance Rate	79 of 84 (94%)	65 of 72 (90%)

- **Interpretations:**
  - There is a high rate of compliance for fenestration products across both Phase I (94%) and Phase III (90%), with a slight decrease in Phase III.
  - This represents one of the most significant findings of the field study, with nearly all of the observations at or above the code requirement.

3.1.1.4 Wall Insulation

The energy performance of a wall insulation system is determined both by the R-value of the insulation installed and the quality of the installation. Given the large number of possible combinations of compliance options and installation qualities, the results are presented as U-factors which allow all relevant aspects to be considered in one metric.

At the start of the overall project, insulation installation quality (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[1] assessment protocol for cavity insulation which has three grades; Grade I being the best quality installation and Grade III being the worst.

Table 3.4 shows the number and percentage of IIQ observations by grade for above grade wall insulation for Phase I and Phase III. The table illustrates that above grade wall IIQ was comparable in both Phase I and Phase III, with Grade I installations accounting for about 60%. The number of Grade III installations did decrease from 8% in Phase I to 3% in Phase III.

Table 3.4. Comparison of Phase I and Phase III Above Grade Wall IIQ for Texas CZ2A

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	38 / 42	19 /27	5 / 2	**62 / 71**
Above Grade Percentages	61% / 59%	31% / 38%	8% / 3%	**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 3.4. In the graph, observations are binned for clearer presentation based on the most commonly observed combinations.

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

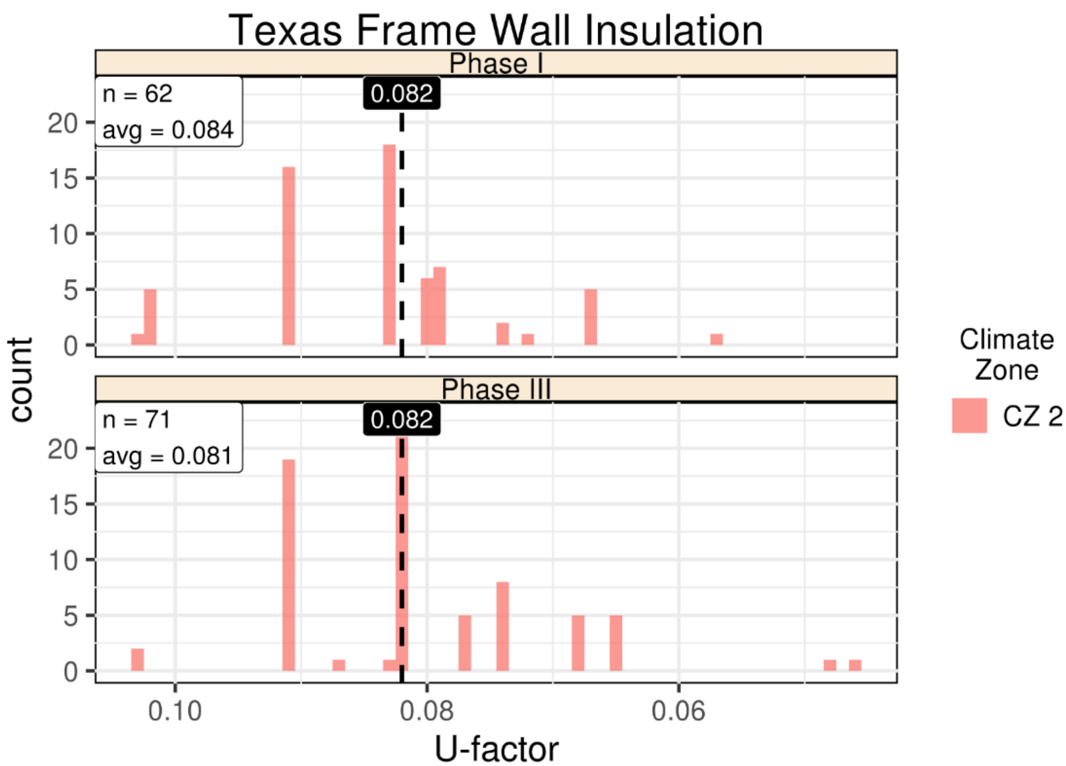

Figure 3.4. Comparison of Phase I and Phase III Wall U-Factors for Texas CZ2A

Table 3.5. Texas CZ2A Wall U-Factors in Phase I and Phase III

Wall U		Phase I	Phase III
Requirement		0.082	0.082
Observations			
	Number	62	71
	Range	0.103 to 0.058	0.103 to 0.046
	Average	0.084	0.081
	Compliance Rate	40 of 62 (65%)	48 of 71 (68%)

- **Interpretations:**
  - The compliance rate for wall U-factor is consistent across phases.

3.1.1.5 Ceiling Insulation

Figure 3.5 represents the observed R-values for Texas ceilings.

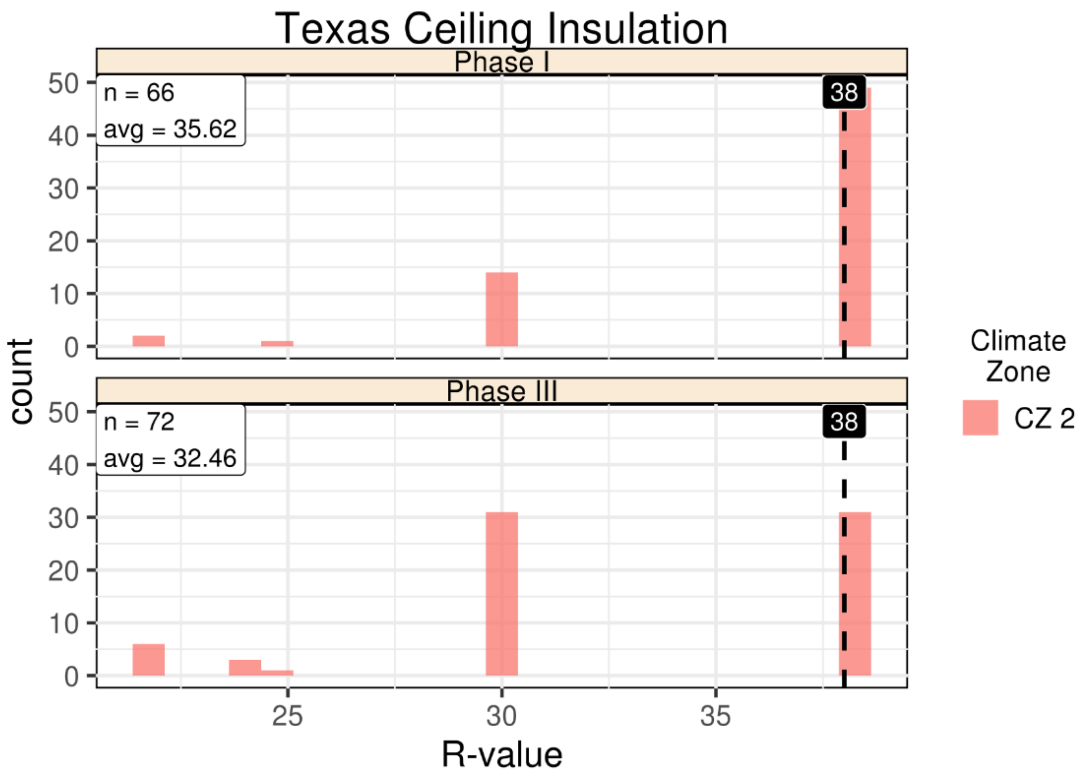

Figure 3.5. Comparison of Phase I and Phase III Ceiling R-Values for Texas CZ2A

Table 3.6. Texas CZ2A Ceiling R-Values in Phase I and Phase III

Ceiling R		Phase I	Phase III
Requirement		R-38	R-38
Observations			
	Number	66	72
	Range	R-22 to R-38	R-22 to R-38
	Average	R-35.6	R-32.5
	Compliance Rate	49 of 66 (74%)	31 of 72 (43%)

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

Table 3.7. Comparison of Phase I and Phase III Roof IIQ for Texas CZ2A

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	36 / 71	11 / 1	2 / 0	**49 / 72**
Roof Cavity Percentages	74% / 99%	22% / 1%	4% / 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 3.6.

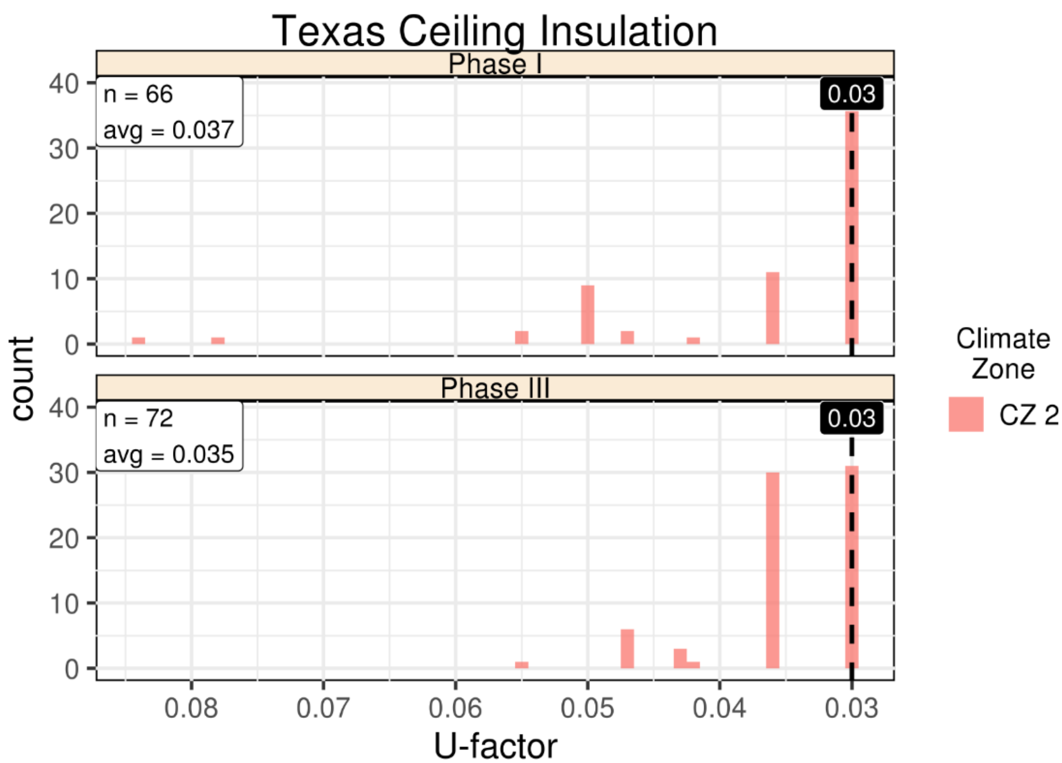

Figure 3.6. Comparison of Phase I and Phase III Ceiling U-Factors for Texas CZ2A

Table 3.8. Texas CZ2A Ceiling U-Factors in Phase I and Phase III

Ceiling U	**Phase I**	**Phase III**
Requirement	0.03	0.03
Observations		
Number	66	72
Range	0.084 to 0.030	0.055 to 0.030
Average	0.037	0.035
Compliance Rate	39 of 66 (59%)	31 of 72 (43%)

- **Interpretations:**
  - The compliance rate for ceiling U-factor decreased from 59% in Phase I to 43% in Phase III. The driver of this decrease appears to be an increase in the number of R-30 ceiling insulation observations, which may be cathedral ceilings and therefore would comply under the 2015 IECC.

3.1.1.6 Lighting

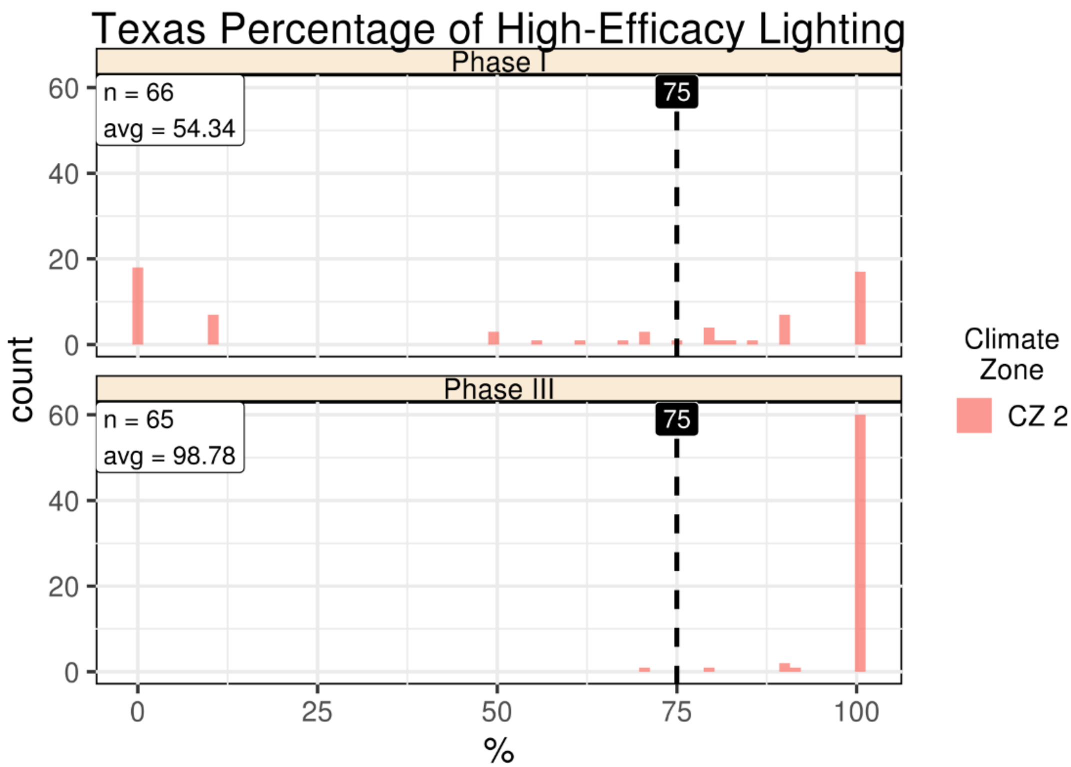

Figure 3.7. Comparison of Phase I and Phase III High-Efficacy Lighting Percentages for Texas CZ2A

Table 3.9. Texas CZ2A High-Efficacy Lighting in Phase I and Phase III

Lighting	Phase I	Phase III
Requirement	75	75
Observations		
Number	66	65
Range	0 to 100	70 to 100
Average	54.3	98.8
Compliance Rate	32 of 66 (48%)	64 of 65 (98%)

- **Interpretations:**
  - A little less than half of the field observations were observed to meet the requirement in Phase I; a much lower number than expected. This represented an area of significant savings potential and was a focus of Phase II education and training activities.
  - There was a significant improvement in Phase III with nearly all of the observations meeting or exceeding the requirement.

3.1.1.7 Duct Tightness

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

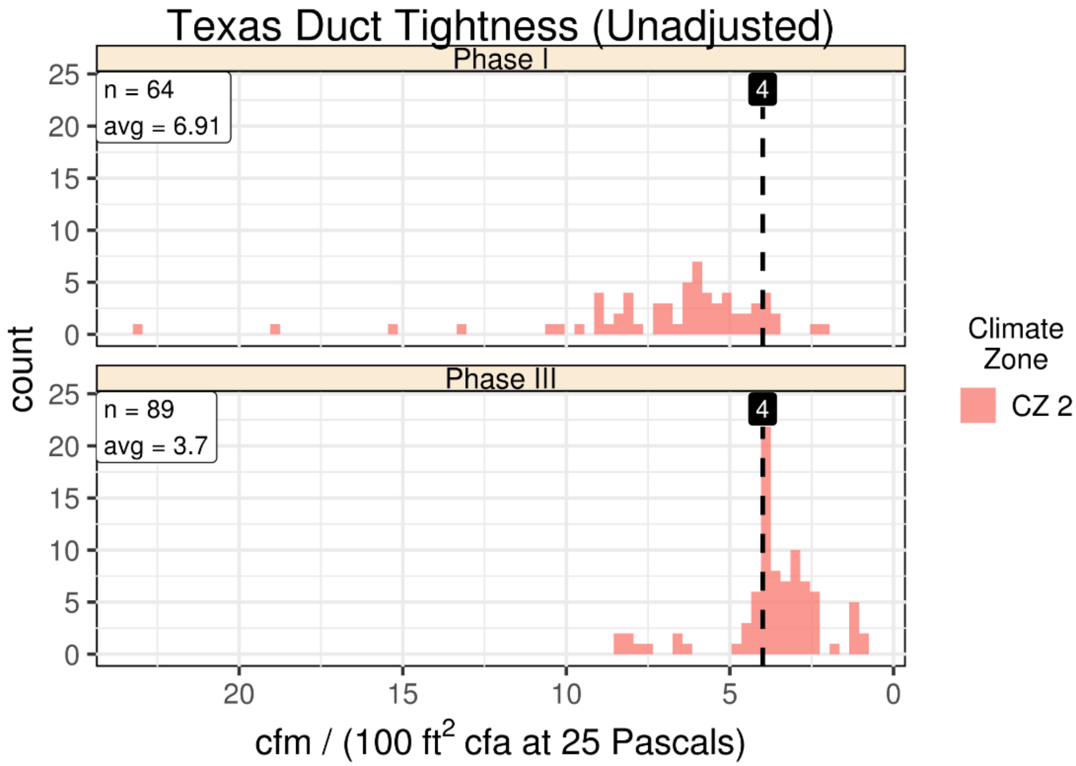

Figure 3.8. Comparison of Phase I and Phase III Duct Tightness Values for Texas CZ2A

Table 3.10. Texas CZ2A Duct Tightness Values in Phase I and Phase III (unadjusted)

Duct Tightness	Phase I	Phase III
Requirement	4.0 CFM25/100ft^2 CFA	4.0 CFM25/100ft^2 CFA
Observations		
Number	64	89
Range	23.0 to 2.0	8.4 to 1.0
Average	6.9	3.7
Compliance Rate	8 of 65 (12%)	70 of 89 (79%)

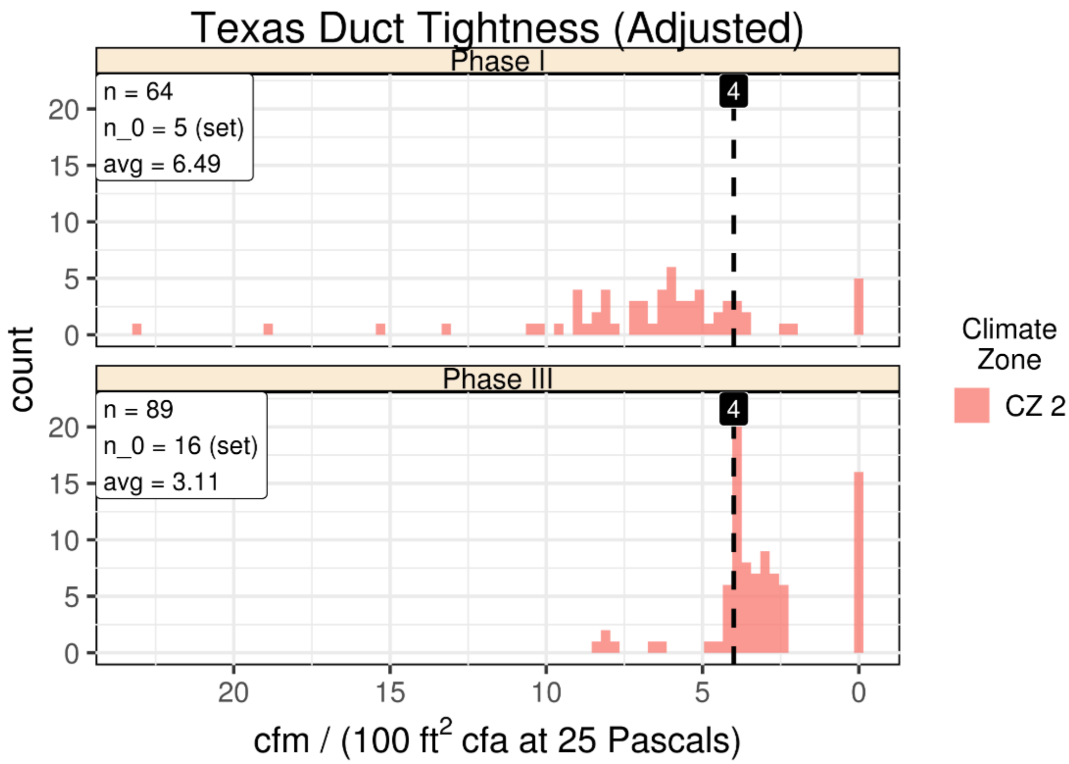

Figure 3.9. Comparison of Phase I and Phase III Adjusted Duct Tightness Values for Texas CZ2A

Table 3.11. Texas CZ2A Duct Tightness Values in Phase I and Phase III (adjusted)

Duct Tightness Adj	**Phase I**	**Phase III**
Requirement	4.0 CFM25/100ft^2 CFA	4.0 CFM25/100ft^2 CFA
Observations		
Number	64	89
Range	23.0 to 0.0	8.3 to 0.0
Average	6.5	3.1
Compliance Rate	12 of 64 (19%)	75 of 89 (84%)

- **Interpretations:**
  - For unadjusted duct tightness, the distribution of Phase I observations exhibited higher leakage than expected compared to the 2015 IECC. There was also a wide range of results. Duct tightness was a focus of Phase II education and training activities, and results improved in Phase III, with the average being less than the code requirement. It is also notable that the number of outliers in the distribution was greatly reduced.
  - For adjusted duct tightness, the situation is similar; the distribution in Phase I had an average above code and a large number of outliers. The Phase III distribution has an average below the current code requirement and a higher number of ducts entirely in conditioned space.

3.1.2 Additional Data Items

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

The following represents a summary of this data and outlines some of the more significant findings, in many cases including the observation or compliance rate associated with the specified item. A larger selection of the additional data items collected as part of the Texas field study is contained in Appendix C. The full data set is also available on the DOE Building Energy Codes Program website.[2]

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

3.1.2.1 Average Home

Table 3.12. Average Home

Home Statistics	Phase I	Phase III
Number of Observations	133	136
Average Square Footage (ft^2)	2708	2680
Number of Stories	1.82	1.77

3.1.2.2 Compliance

In Phase I, the majority of homes were permitted under the 2009 IRC (89%) or 2012 IECC (11%). In Phase III, all homes were permitted under the 2015 IECC. Approximately one-quarter of the homes (26%) participated in an above-code program[3] in Phase I while none were noted in Phase III.

3.1.2.3 Envelope

Table 3.13. Envelope

Requirement	Phase I	Phase III
Profile		
Walls	All wood-framed with mix of 4” (97%) and 6” (3%), (n=133)	All wood-framed with mix of 4” (97%) and 6” (3%), (n=136)
Foundations	All slab-on-grade (n=133)	All slab-on-grade (n=136)
Insulation labeled	97% (n=77)	99% (n=70)
Lighting fixtures sealed	98% (n=98)	100% (n=55)
Utility penetrations sealed	93% (n=101)	100% (n=71)
Dropped ceilings sealed	26% (n=70)	93% (n=54)

[2] Available at https://www.energycodes.gov/compliance/energy-code-field-studies.
[3] No specific above-code programs were noted

Requirement	Phase I	Phase III
Knee walls sealed	67% (n=73)	96% (n=75)
Behind tubs and showers sealed	70% (n=83)	91% (n=68)
Attic hatches and doors complied	42% (n=50)	93% (n=83)

3.1.2.4 Duct & Piping Systems

Table 3.14. Duct and Piping Systems

Requirement	Phase I	Phase III
Profile		
Supply ducts located within conditioned space (percentage of duct system)	34% (n=134)	41% (n=165)
Return ducts located within conditioned space (percentage of duct system)	34% (n=134)	40% (n=165)
Supply ducts entirely within conditioned space (percentage of homes and number)	5% (7 homes)	16% (27 homes)
Return ducts entirely within conditioned space (percentage of homes and number)	7% (9 homes)	16% (27 homes)
Duct Insulation[4]	R-6.1 (n=273)	R-6.1 (n=282)
Pipe Insulation	R-2.7 (n=126)	R-3 (n=97)
Building cavities not used as supply ducts	100% (n=113)	99% (n=136)
Air ducts sealed	83% (n=111)	98% (n=136)
Air handlers sealed	90% (n=129)	97% (n=134)
Filter boxes sealed	90% (n=129)	98% (n=134)

Successes

As a percentage of compliant observations, nearly all areas improved in Phase III.

3.1.2.5 HVAC Equipment

Table 3.15. HVAC Equipment

Requirement	Phase I	Phase III
Profile		
Heating equipment type	Mostly gas furnaces (89%), 7% electric furnace, and 5% heat pump (n=122)	Gas furnaces (94%), 4% electric furnace, 2% heat pump (n=165)
Heating equipment efficiency	83 AFUE gas furnace, 81 AFUE electric furnaces, 8.8 SEER heat pump (n=88)	82 AFUE (n=140) (number reported for gas furnaces only - heat pumps and electric furnaces reported at 100)

[4] The number of observations for duct insulation include roughly 273 individual observations in Phase I and 282 in Phase III for both supply and return ducts in attics and in unconditioned space.

Requirement	Phase I	Phase III
Cooling equipment type	Majority (94%) central AC, 5% heat pump, 1% room AC (n=116)	All central AC (n=115)
Cooling equipment efficiency	15.1 SEER	14.7 SEER
Water heating equipment type	Mostly gas storage (85%), 9% electric storage, and 6% gas tankless (n=114)	Gas storage 67%, gas tankless 20%, electric storage 13%, (n=85)
Water heating equipment capacity	54 gallons (n=102)	49 gallons (n=64)
Water heating equipment efficiency	EF 0.65 (n=65)	EF 0.67 (n=16)

3.2 Energy Use Intensity

The energy analysis results in Figure 3.10 based on Texas CZ2A show an estimated decrease in EUI between Phase I and III of 1.83 kBtu/ft^2, which surpasses the 1.25 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 the 2015 IECC prescriptive code requirements. Average energy consumption decreased by approximately 8.1% between Phase I and Phase III. Table 3.16 compares the Phase I and Phase III results.

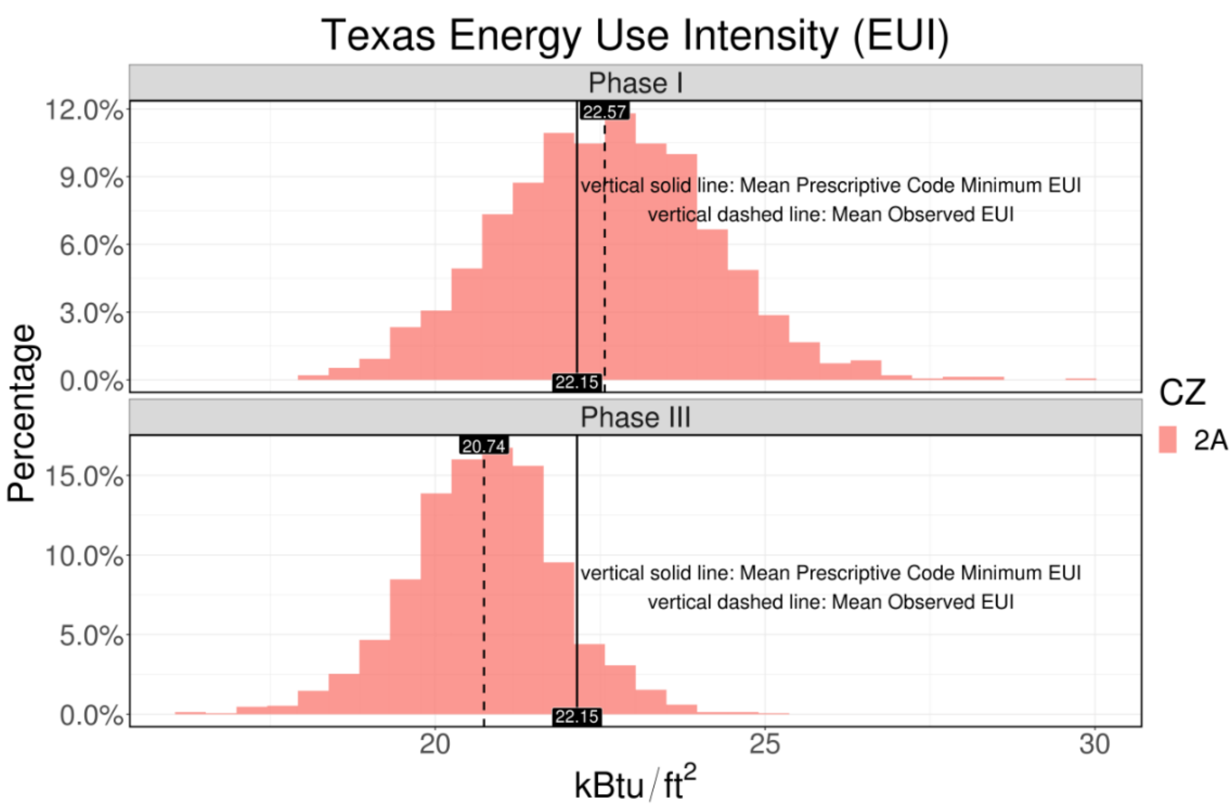

Figure 3.10. Comparison of Phase I and Phase III EUI for Texas CZ2A

Table 3.16. Texas CZ2A EUI in Phase I and Phase III

Prescriptive EUI[5]	Phase I	Differential (Phase I vs. Prescriptive)	Phase III	Differential (Phase III vs. Prescriptive)	% Change (Phase III vs. I)
22.15	22.57	+1.9%	20.74	-6.4%	-8.1%

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[6], shown below followed by the percent that met code, were further analyzed to estimate the associated savings potential for energy, cost and environmental impacts.

Table 3.17. Comparison of Phase I and Phase III Compliance Rates by Measure in Texas CZ2A

Measure	Phase I Compliance Rate	Phase III Compliance Rate	Phase III to Phase I Difference in Compliance Rate
Envelope Air Tightness	60%	92%	+32%
Exterior Wall Insulation	65%	68%	+3%
Duct Tightness[7]	19%	84%	+65%
Lighting	48%	98%	+50%
Ceiling Insulation	59%	43%	-16%

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

The results for the energy, cost, and environmental savings potential estimates are shown in Table 3.18. The results indicate that the Phase II education and training activities were successful in reducing the overall savings potential for all measures except ceiling insulation. Improvement is measured by a reduction in measure-level savings potential between Phase I and Phase III.

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

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

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

Table 3.18. Comparison of Phase I and Phase III Estimated Annual Savings Potential Texas CZ2A

	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**
Envelope Air Tightness	39,493	10,295	654,623	170,471	15,910	4,135
Exterior Wall Insulation	27,090	19,009	511,748	359,086	15,239	10,692
Duct Tightness	89,058	7,896	1,914,867	170,171	66,132	5,891
Lighting	40,483	105	1,550,412	4,050	76,960	202
Ceiling Insulation	10,942	27,367	216,147	540,180	6,806	16,994
TOTAL	**207,065**	**64,672**	**$4,847,797**	**$1,243,958**	**181,047**	**37,914**

Overall measure-level energy cost savings potential showed a 74% reduction between Phase I and Phase III. To reflect the longer-term cost savings potential of improved compliance, annual savings were accumulated over 5, 10, and 30 years of new construction (Table 3.19). See Appendix D for additional details on electricity savings and natural gas savings per home associated with each measure; savings by individual foundation components; and how the total savings and emissions reductions accumulate over 5, 10, and 30 years of construction. See Appendix E for measure level savings results extrapolated to Texas Statewide.

Table 3.19. Comparison of Five-years, Ten-years, and Thirty-years Cumulative Annual Savings Potential in Texas CZ2A 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**
Envelope Air Tightness	9,819,345	2,557,065	36,004,265	9,375,905	304,399,695	79,269,015
Exterior Wall Insulation	7,676,220	5,386,290	28,146,140	19,749,730	237,962,820	166,974,990
Duct Tightness	28,723,005	2,552,565	105,317,685	9,359,405	890,413,155	79,129,515
Lighting	23,256,180	60,750	85,272,660	222,750	720,941,580	1,883,250
Ceiling Insulation	3,242,205	8,102,700	11,888,085	29,709,900	100,508,355	251,183,700
TOTAL	72,716,955	18,659,370	266,628,835	68,417,690	2,254,225,605	578,440,470

4.0 Conclusions

The Texas field study is unique in that data was not collected statewide and the state experienced a code change during the project. Given both the large geographic size and population of Texas, the project team decided to limit data collection to an area comprising 30 counties in south central and southeast Texas anchored on Houston (all CZ2A). It includes dense metropolitan areas, small- to mid-size cities and towns and unincorporated areas of counties and has a population of approximately 7 million, about 25% of the state population and approximately 50% of the new residential permits in the state.

For purposes of the study, stakeholders agreed that this area could be used to represent the entire state as it includes a broad range of the energy codes in use and levels of enforcement seen across the state. At the project team's request, the analytical results were calculated in two ways: CZ2A results only and results extrapolated statewide from the CZ2A data. For the statewide results, the CZ2A data were used as observed values in all of the climate zones and analytical results were extrapolated statewide. This extrapolation was repeated in Phase III. See Section 2.4.1 for additional details. The results in the main body of this report are presented for the CZ2A data. Statewide results are presented in Appendix E.

At the time of Phase I data collection, the state had the 2009 IECC, but had moved to the 2015 IECC before Phase III. Therefore, the Phase I data was collected from homes permitted under the 2009 code, while the Phase III data was collected from homes permitted under the 2015 code. However, Phase I savings potential was calculated against the 2015 code as that was the code that homes would need to comply with in the future, and so a direct comparison between Phase I and Phase III savings potential can be made.

The Texas field study successfully achieved a measurable decrease in statewide energy consumption and a reduction in measure-level savings potential through targeted education and training. A reduction in savings potential equates to improvement. Based on the study's findings, the prototypical, newly constructed home in Texas consumes 6.4 percent less energy than a home exactly meeting the state energy code. As shown in Table 4.1, the average home showed an estimated improvement in energy performance of approximately 8.1 percent between Phase I and III.

Table 4.1. Average Modeled Energy Use Intensity in Texas CZ2A (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)
22.15	22.57	+1.9%	20.74	-6.4%	-8.1%

This results in over $3.6 million in annual achieved savings, an improvement of 74% following the Phase II targeted education and training activities (Table 4.2).[2]

[1] Calculated based on the minimum prescriptive requirements of the state energy code.
[2] See Table 3.18 for potential total energy cost savings in each phase.

Table 4.2. Estimated Annual Cost Savings Potential in Texas CZ2A

Measure	% Change Phase III vs. I
Envelope Air Tightness	-74.0%
Exterior Wall Insulation	-29.8%
Duct Tightness	-91.1%
Lighting	-99.7%
Ceiling Insulation	+149.9%
TOTAL	**-74.3%**

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

5.0 References

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

DOE Building Energy Codes Program's residential field study website is available at https://www.energycodes.gov/residential-energy-code-field-studies.

DOE 2018. "Residential Building Energy Code Field Study: Data Collection and Analysis." Available at https://www.energy.gov/eere/buildings/downloads/energy-code-field-studies

EnergyPlus. https://energyplus.net/.

The Texas residential field study website is available at https://eepartnership.org/program-areas/energy-codes-2/energy-codes/houston-field-study/ (accessed September 17, 2020).

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

Appendix A

Stakeholder Participation

Appendix A

Stakeholder Participation

A.1 Stakeholder Participation

Table A.1. Stakeholder Participation in Project Kickoff Meeting

Stakeholder	Description
TX State Energy Conservation Office (SECO)	Key state agency responsible for regulating code adoption and compliance in Texas. SECO manages and allocates resources for training and outreach regarding codes.
Electric Utility Marketing Managers of Texas (EUMMOT)	The industry group that oversees the development and implementation of energy efficiency programs and incentives for investor owned electric utilities in TX
International Code Council local chapters, Brazos Valley Inspectors' Association, Bay Area Inspectors' Association, Bluebonnet Inspectors' Association and Golden Triangle Inspectors' Association	Represent building officials in the TX Field Study area and act as the anchors for the Regional Working Groups. Regional Working Groups hosted trainings, acted as a conduit to code officials and generally provided promotion and support for the project.
Greater Houston Home Builders' Association (GHBA)	The organization that represents a large number of the homebuilders who participated in the Field Study

Appendix B

State Sampling Plan

Appendix B

State Sampling Plan

B.1 State Sampling Plan

Table B.1. Phase I State Sampling Plan

Location	Sample	Actual*
Harris County Unincorporated Area, Harris	13	13
Fort Bend County Unincorporated Area, Fort Bend	5	5
Montgomery County Unincorporated Area, Montgomery	3	3
Houston, Harris	17	17
Pearland, Brazoria	5	**6**
League City, Galveston	3	**4.5**
College Station, Brazos	2	2
Fulshear, Fort Bend	1	1
Conroe, Montgomery	2	2
Beaumont, Jefferson	3	**2**
Galveston, Galveston	1	**3**
Port Arthur, Jefferson	1	1
Texas City, Galveston	1	**1.5**
Baytown, Harris	1	1
Katy, Harris	1	1
Alvin, Brazoria	1	1
Dickinson, Galveston	1	**0**
Lumberton, Hardin	1	**2**
Pasadena, Harris	1	**0**
Total	**63**	**66**

*Counts marked in bold indicate a substitution was made in Phase I.

Table B.2. Phase III State Sampling Plan

Location	Sample	Actual
Houston, Harris County	16	16
Harris County Unincorporated Area, Harris County	9	9
Fort Bend County Unincorporated Area, Fort Bend County	8	8
Montgomery County Unincorporated Area, Montgomery County	4	4
Pearland, Brazoria County	2	2
League City, Galveston County	2	2
College Station, Brazos County	5	5

Location	Sample	Actual
Fulshear, Fort Bend County	3	2
Conroe, Montgomery County	2	2
Missouri City, Fort Bend County	2	2
Rosenberg, Fort Bend County	3	3
Texas City, Galveston County	1	1
Beaumont, Jefferson County	1	1
Baytown, Harris County	1	1
Galveston, Galveston County	1	0
Friendswood, Galveston County	1	1
Bellaire, Harris County	1	1
La Porte, Harris County	1	1
Huntsville, Walker County	0	1
Brookshire, Waller County	0	1
Total	**63**	**63**

B.2 Substitutions

In Phase I, several locations targeted by the original sampling plan (as illustrated in Table B.1 above) could not be met due to a lack of either available homes or builder cooperation. For each of these locations, alternatives (listed below) were determined to have the same socioeconomic and demographic characteristics. The project team, following DOE guidelines on substitutions, consolidated the alternatives and considered them as one location for sampling purposes. The numbers in parentheses repeat the data in the "Sample" and "Actual" column in Table B.1[1] to illustrate what was originally targeted compared to what was successfully collected:

- Beaumont (3/2), Lumberton (1/2)
- Pasadena (1/0), Pearland (5/6)
- Galveston (1/3), League City (3/4.5), Texas City (1/1.5).

In Phase III, DOE had revised its methodology to no longer accept "partial" replacements (as collected in various Texas cities in Phase I). The project team had issues with sampling in several locations. Specifically, problems were experienced in Galveston and Fulshear and substitutions were made.

The data collection team was unable to obtain one of the three final site visits in Fulshear due to a lack of available homes at the final stage of construction. The team heavily researched building practices in Fulshear and found that most new construction in that area was occurring in Brookshire, a town roughly five miles north of Fulshear. SPEER confirmed that increased building in Brookshire was due to the expansion of Fulshear and that the same builders were building in the two cities, using the same subcontractors, materials, and technologies. The team also confirmed with SPEER that Brookshire is similar to Fulshear in size, growth, and socioeconomic measures, and would serve as the best substitute for Fulshear. As such, the team obtained one of the three required full data sets in Fulshear from Brookshire (insulation and final) and completed the other two full data sets from Fulshear, as sampled.

[1] A partial sample (e.g., 1.5) indicates that not all of the key items were collected.

The data collection team found that construction practices in Galveston include a stilt-style home that is not prevalent in other areas of the state. Since the purpose of the study is to gather data representative of construction throughout the state, the team sought a substitute for Galveston. The team gathered one complete data set from Huntsville.

B.3 Oversampling

The data collection team oversampled in five jurisdictions; this is due to the use of substitutions and having two teams in the field at one time. The following cities or counties were oversampled:

- Conroe
- Fulshear
- Pearland
- Montgomery County
- Rosenberg.

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 Texas 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
Number of Observations	133	136
Average Square Footage (ft^2)	2708	2680
Number of Stories	1.8	1.8

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%	21%	49%	22%	7%
Percentage (Phase III)	2%	23%	45%	20%	10%

Table C.3. Number of Stories

No. of Stories	1	2	3	4+
Percentage (Phase I)	39%	39%	22%	0%
Percentage (Phase III)	38%	50%	10%	2%

[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			125	136
Frame Walls	99%	100%		
Mass Walls	1%	0%		
Framing Material			132	72
Wood	100%	100%		
Steel	0%	0%		
Framing Depth			133	72
4 inch	97%	97%		
6 inch	3%	3%		
Type of Wall Insulation			62	71
Cavity Only	81%	77%		
Cavity + Continuous	19%	23%		
Continuous Only	0%	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			133	136
Slab on Grade	100%	100%		

C.1.1.4 Builder Profile

Table C.6. Builder Characteristics

Builder Characteristic	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Number of Homes Built Annually	61	NA*	36	NA*
Distribution of Number of Homes Built Annually			36	NA*
Less than 10	3%	NA*		
10 to 50	28%	NA*		
50 to 99	61%	NA*		
100+	8%	NA*		

*Data not collected

C.1.2 Compliance

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

C.1.2.1 Energy Code Used

Table C.7. Energy Code and Above Code Programs

Code or Above Code Program Used	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Energy Code Used			38	136
2009 IECC	89%	0%		
2012 IECC	11%	0%		
2015 IECC	0%	100%		
Was home participating in an above code program?			35*	83*
Yes	26%	0%		
No	74%	100%		

*No specific above-code programs were reported

C.1.3 Envelope

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

Table C.8. Thermal Envelope Characteristics

Thermal Envelope Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Was insulation labeled?			75	70
Yes	97%	99%		
No	3%	1%		
Did the attic hatch/door exhibit the correct insulation value?[1]			50	64
Yes	42%	2%		
No	58%	98%		
Air Sealing in accordance with checklist[2]				
Thermal Envelope sealed?	74%	59%	82	71
Fenestration Sealed?	96%	100%	53	23

[1] The project team noted that the question was phrased slightly differently in Phase III, and the data collection team had a different interpretation of what constituted "correct."

[2] 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
Openings around doors and windows sealed?	96%	96%	83	71
Utility penetrations sealed?	93%	100%	101	71
Dropped ceilings sealed?	74%	93%	70	54
Knee walls sealed?	67%	96%	73	75
Garage walls sealed?	92%	65%	51	40
Tubs and showers sealed?	92%	91%	83	68
Attic access openings sealed?	82%	93%	55	83
Rim joists sealed?	87%	94%	70	51
Other sources of infiltration sealed?	71%	84%	89	70
IC-rated light fixtures sealed?	98%	100%	98	55

C.1.4 Duct & Piping Systems

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

Table C.9. Duct & Piping System Characteristics

Duct & Piping System Characteristic	Phase I Observations	Phase IIII Observations	Number of Phase I Observations	Number of Phase III Observations
Duct location in conditioned space (average percentage)				
Supply	34%	41%	134	165
Return	34%	40%	134	165
Ducts entirely in conditioned space (number and percentage)				
Supply	7 (5%)	27 (16%)	134	165
Return	9 (7%)	27 (16%)	134	165
Ducts in unconditioned space insulation (R-value)				
Supply	6	6	12	23
Return	6	6	11	23
Ducts in attic insulation (R-value)				
Supply	6.1	6.2	128	118
Return	6.1	6.2	128	118
Pipe insulation (R-value)			126	
Average	R-2.7	R-3	126	97
Range	R-2 to R-3	R-3 to R-3	126	97
Building cavities used as supply ducts	0%	1%	113	136
Air ducts sealed	83%	98%	111	136
Air handlers sealed	90%	97%	129	134
Filter boxes sealed	90%	98%	129	134

C.1.5 HVAC Equipment

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

C.1.5.1 Heating

Table C.10. Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			124	125
Gas	89%	93%		
Electricity	11%	7%		
System Type			122	165
Furnace	95%	98%		
Heat Pump	5%	2%		
Average System Capacity			77	137
Furnace	83,000 Btu/hr	73,100 Btu/hr		
Heat Pump	54,000 Btu/hr	22,750 Btu/hr		
Average System Efficiency			122	140
Furnace	83 AFUE	82 AFUE		
Heat Pump	8.8 HSPF	NA*		

*Heat pumps and electric furnaces listed as “100”

C.1.5.2 Cooling

Table C.11. Cooling Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			116	115
Central AC	94%	100%		
Heat Pump	5%	0%		
Room AC	1%	0%		
Average System Capacity			73	86
Central AC	52,800 Btu/hr	39,600 Btu/hr		
Heat Pump	50,000 Btu/hr	NA		
Room AC	60,000 Btu/hr			
Average System Efficiency			70	88
Central AC	15 SEER	14.7 SEER		
Heat Pump	16 SEER	NA		
Room AC	14 SEER	NA		

C.1.5.3 Water Heating

Table C.12. Water Heating Equipment Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
Fuel Source			115	102
Gas	94%	88%		
Electricity	6%	12%		
System Type			114	85
Storage	91%	80%		
Tankless	9%	20%		
Average System Capacity	54 gal	49 gal	102	64
Average System Efficiency			69	16
Electric Storage (non-heat pump)	EF 0.86	EF 0.92		
Gas Storage	EF 0.63	EF 0.63		
Gas Tankless	EF 0.69	NA		

Table C.13. Water Heating System Storage Capacity Distribution

Capacity	< 50 gal	50-59 gal	60-69 gal	70-79 gal	80-89 gal	90+ gal
Phase I Percentage	26%	53%	0%	0%	18%	3%
Phase III Percentage	97%	0%	0%	0%	1.5%	1.5%[1]

C.1.5.4 Ventilation

Table C.14. Ventilation Characteristics

Item	Phase I Observations	Phase III Observations	Number of Phase I Observations	Number of Phase III Observations
System Type			101	118
Exhaust Only	84%	27%		
AHU-Integrated	16%	73%[2]		
Exhaust Fan Type			85	32
Dedicated Exhaust	0%	3%		
Bathroom Fan	100%	97%		

[1] The project team speculated that the shift in capacity size from Phase I to Phase III may be due to a change in standards.

[2] The project team noted that going from the 2009 IECC to the 2015 in CZ2 triggers ventilation which was previously not required and is likely the reason for the shift between Phase I and Phase III. Additionally, the 16% in Phase I was likely from a jurisdiction on the 2012 IECC, which was the first to require ventilation in CZ2.

Appendix D

Energy Savings

Appendix D

Energy Savings

D.1 Measure-Level Savings

This appendix contains detailed measure-level annual savings results based on CZ2A for both Phase I (Table D.1 and Phase III (Table D.2) for Texas. Also included are multi-year (5-year, 10-year, and 30-year) aggregations of the annual results in Table D.3, Table D.4, and Table D.5. The multi-year savings reflect the same reductions and increases as the annual savings and are simply the annual savings multiplied by 15, 55, and 465 for 5-year, 10-year, and 30-year savings, respectively. For analytical details refer to Section 2.3.3 (Savings Analysis) or the methodology report (DOE 2018). See Appendix E for results based on a statewide extrapolation of CZ2A results.

Table D.1. Phase I Annual Measure-Level Savings Potential for Texas CZ2A

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Tightness	54	5	719	54,937	39,493	654,623	15,910
Exterior Wall Insulation	52	3	493	54,937	27,090	511,748	15,239
Duct Tightness	226	9	1,621	54,937	89,058	1,914,867	66,132
Lighting*	264	-2	737	54,937	40,483	1,550,412	76,960
Ceiling Insulation	23	1	199	54,937	10,942	216,147	6,806
TOTAL	**619**	**17**	**3769**	**54,937**	**207,065**	**4,847,797**	**181,047**

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

Table D.2. Phase III Annual Measure-Level Savings Potential for Texas CZ2A

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Tightness	14	1	187	54,937	10,295	170,471	4,135
Exterior Wall Insulation	36	2	346	54,937	19,009	359,086	10,692
Duct Tightness	20	1	144	54,937	7,896	170,171	5,891
Lighting*	1	0	2	54,937	105	4,050	202
Ceiling Insulation	58	3	498	54,937	27,367	540,180	16,994
TOTAL	**129**	**7**	**1,178**	**54,937**	**64,673**	**1,243,958**	**37,913**

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

Table D.3. Phase I Five-years, Ten-years, and Thirty-years Cumulative Annual Savings Potential for Texas CZ2A

	Total Energy Savings (MMBtu)			**Total Energy Cost Savings ($)**			**Total State Emissions Reduction (MT CO2e)**		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Envelope Air Tightness	592,395	2,172,115	18,364,245	9,819,345	36,004,265	304,399,695	238,650	875,050	7,398,150
Exterior Wall Insulation	406,350	1,489,950	12,596,850	7,676,220	28,146,140	237,962,820	228,585	838,145	7,086,135
Duct Tightness	1,335,870	4,898,190	41,411,970	28,723,005	105,317,685	890,413,155	991,980	3,637,260	30,751,380
Lighting	607,245	2,226,565	18,824,595	23,256,180	85,272,660	720,941,580	1,154,400	4,232,800	35,786,400
Ceiling Insulation	164,130	601,810	5,088,030	3,242,205	11,888,085	100,508,355	102,090	374,330	3,164,790
TOTAL	3,105,975	11,388,575	96,285,225	72,716,955	266,628,835	2,254,225,605	2,715,705	9,957,585	84,186,855

Table D.4. Phase III Five-years, Ten-years, and Thirty-years Cumulative Annual Savings Potential for Texas CZ2A

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Envelope Air Tightness	154,425	566,225	4,787,175	2,557,065	9,375,905	79,269,015	62,025	227,425	1,922,775
Exterior Wall Insulation	285,135	1,045,495	8,839,185	5,386,290	19,749,730	166,974,990	160,380	588,060	4,971,780
Duct Tightness	118,440	434,280	3,671,640	2,552,565	9,359,405	79,129,515	88,365	324,005	2,739,315
Lighting	1,575	5,775	48,825	60,750	222,750	1,883,250	3,030	11,110	93,930
Ceiling Insulation	410,505	1,505,185	12,725,655	8,102,700	29,709,900	251,183,700	254,910	934,670	7,902,210
TOTAL	970,095	3,557,015	30,072,945	18,659,370	68,417,690	578,440,470	568,695	2,085,215	17,629,545

Table D.5. Difference between Five-years, Ten-years, and Thirty-years Cumulative Annual Texas CZ2A 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**
Envelope Air Tightness	437,970	1,605,890	13,577,070	7,262,280	26,628,360	225,130,680	176,625	647,625	5,475,375
Exterior Wall Insulation	121,215	444,455	3,757,665	2,289,930	8,396,410	70,987,830	68,205	250,085	2,114,355
Duct Tightness	1,217,430	4,463,910	37,740,330	26,170,440	95,958,280	811,283,640	903,615	3,313,255	28,012,065
Lighting	605,670	2,220,790	18,775,770	23,195,430	85,049,910	719,058,330	1,151,370	4,221,690	35,692,470
Ceiling Insulation	-246,375	-903,375	-7,637,62	-4,860,495	-17,821,815	-150,675,345	-152,820	-560,340	-4,737,420
TOTAL	2,135,880	7,831,560	66,212,280	54,057,585	198,211,145	1,675,785,135	2,147,010	7,872,370	66,557,310

Appendix E

Statewide Results

Appendix E

Statewide Results

As noted previously, the results shown in the main body of the report are based only on CZ2A. The project team and the stakeholders were also interested in results assuming construction trends would remain similar across climate zones. This appendix includes the extrapolated statewide EUI and measure savings results.

E.1 Statewide Energy Use Intensity

The energy analysis results in Figure E.1 based on extrapolated statewide results show an estimated decrease in EUI between Phase I and II of 2.07 kBtu/ft^2, which surpasses the 1.25 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. Average energy consumption decreased by over 9% between Phase I and Phase III. Table E.1 compares the Phase I and Phase III results.

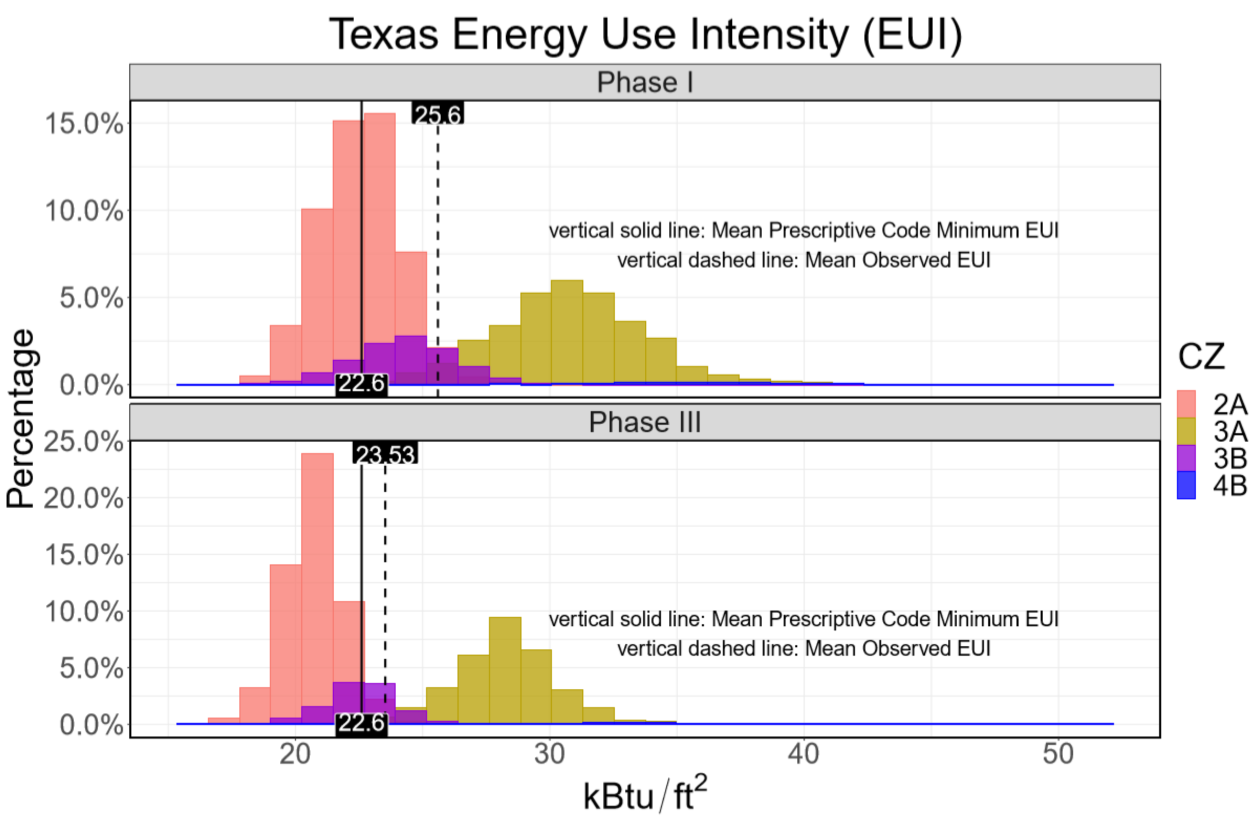

Figure E.1. Comparison of Phase I and Phase III Statewide EUI for Texas Statewide

Table E.1. Texas 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)
22.6	25.6	-13.3%	23.53	-4.1%	9.2%

E.2 Statewide Savings Potential

Table E.2. Comparison of Phase I and Phase III Estimated Annual Savings Potential Texas Statewide

	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**
Envelope Air Tightness	314,889	217,253	4,656,869	3,179,965	88,045	58,441
Exterior Wall Insulation	293,040	258,485	5,029,864	4,426,562	129,948	113,892
Duct Tightness	181,188	15,958	3,582,893	316,613	112,965	10,021
Lighting	70,571	183	2,774,421	7,249	139,105	364
Ceiling Insulation	23,677	58,222	443,058	1,090,432	13,027	32,095
TOTAL	**883,365**	**550,101**	**16,487,105**	**9,020,821**	**483,090**	**214,811**

Detailed measure-level annual savings results based on statewide extrapolation are provided for both Phase I (Table E.4) and Phase III (Table E.5) for Texas. Also included are multi-year (5-year, 10-year, and 30-year) aggregations of the annual results in Table E.6, Table E.7, and Table E.8. 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). See Appendix D for results based on CZ2A results.

Table E.3. Estimated Annual Statewide Savings Potential Texas Statewide

	Total Energy Cost Savings Potential ($)		$ Change	% Change
Measure	**Phase I**	**Phase III**	**Phase III vs. I**	**Phase III vs. I**
Envelope Air Tightness	4,656,869	3,179,965	1,476,904	31.7%
Exterior Wall Insulation	5,029,864	4,426,562	603,302	12.0
Duct Tightness	3,582,893	316,613	3,266,280	91.1
Lighting	2,774,421	7,249	2,767,172	99.7
Ceiling Insulation	443,058	1,090,432	-647,374	-146.1%
TOTAL	**$16,487,105**	**$9,020,821**	**$7,466,284**	**45.2%**

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

Table E.4. Phase I Statewide Annual Measure-Level Savings Potential for Texas Statewide

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Tightness	162	26	3,130	100,608	314,889	4,656,869	88,045
Exterior Wall Insulation	241	21	2,913	100,608	293,040	5,029,864	129,948
Duct Tightness	210	11	1,801	100,608	181,188	3,582,893	112,965
Lighting*	261	-2	701	100,608	70,571	2,774,421	139,105
Ceiling Insulation	24	2	235	100,608	23,677	443,058	13,027
TOTAL	**898**	**58**	**8,780**	**100,608**	**883,365**	**16,487,105**	**483,090**

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

Table E.5. Phase III Statewide Annual Measure-Level Savings Potential for Texas Statewide

Measure	Electricity Savings (kWh/ home)	Natural Gas Savings (therms/ home)	Total Savings (kBtu/ home)	Number of Homes	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Envelope Air Tightness	106	18	2,141	100,608	217,253	3,179,965	58,441
Exterior Wall Insulation	210	18	2,549	100,608	258,485	4,426,562	113,892
Duct Tightness	19	1	158	100,608	15,958	316,613	10,021
Lighting*	1	0	2	100,608	183	7,249	364
Ceiling Insulation	60	4	577	100,608	58,222	1,090,432	32,095
TOTAL	**395**	**41**	**5,427**	**100,608**	**550,101**	**9,020,821**	**214,811**

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

Table E.6. Phase I Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Potential for Texas Statewide

	Total Energy Savings (MMBtu)			**Total Energy Cost Savings ($)**			**Total State Emissions Reduction (MT CO2e)**		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Envelope Air Tightness	4,723,335	17,318,895	146,423,385	69,853,035	256,127,795	2,165,444,085	1,320,675	4,842,475	40,940,925
Exterior Wall Insulation	4,395,600	16,117,200	136,263,600	75,447,960	276,642,520	2,338,886,760	1,949,220	7,147,140	60,425,820
Duct Tightness	2,717,820	9,965,340	84,252,420	53,743,395	197,059,115	1,666,045,245	1,694,475	6,213,075	52,528,725
Lighting	1,058,565	3,881,405	32,815,515	41,616,315	152,593,155	1,290,105,765	2,086,575	7,650,775	64,683,825
Ceiling Insulation	355,155	1,302,235	11,009,805	6,645,870	24,368,190	206,021,970	195,405	716,485	6,057,555
TOTAL	**13,250,475**	**48,585,075**	**410,764,725**	**247,306,575**	**906,790,775**	**7,666,503,825**	**7,246,350**	**26,569,950**	**224,636,850**

Table E.7. Phase III Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Potential for Texas Statewide

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
	5yr	10yr	30yr	5yr	10yr	30yr	5yr	10yr	30yr
Envelope Air Tightness	3,258,795	11,948,915	101,022,645	47,699,475	174,898,075	1,478,683,725	876,615	3,214,255	27,175,065
Exterior Wall Insulation	3,877,275	14,216,675	120,195,525	66,398,430	243,460,910	2,058,351,330	1,708,380	6,264,060	52,959,780
Duct Tightness	239,370	877,690	7,420,470	4,749,195	17,413,715	147,225,045	150,315	551,155	4,659,765
Lighting	2,745	10,065	85,095	108,735	398,695	3,370,785	5,460	20,020	169,260
Ceiling Insulation	873,330	3,202,210	27,073,230	16,356,480	59,973,760	507,050,880	481,425	1,765,225	14,924,175
TOTAL	**8,251,515**	**30,255,555**	**255,796,965**	**135,312,315**	**496,145,155**	**4,194,681,765**	**3,222,195**	**11,814,715**	**99,888,045**

Table E.8. Difference between Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings Potential Texas Statewide Phase III vs. Phase I

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
	5yr	10yr	30yr	5yr	10yr	30yr	5yr	10yr	30yr
Envelope Air Tightness	1,464,540	5,369,980	45,400,740	22,153,560	81,229,720	686,760,360	444,060	1,628,220	13,765,860
Exterior Wall Insulation	518,325	1,900,525	16,068,075	9,049,530	33,181,610	280,535,430	240,840	883,080	7,466,040
Duct Tightness	2,478,450	9,087,650	76,831,950	48,994,200	179,645,400	1,518,820,200	1,544,160	5,661,920	47,868,960
Lighting	1,055,820	3,871,340	32,730,420	41,507,580	152,194,460	1,286,734,980	2,081,115	7,630,755	64,514,565
Ceiling Insulation	-518,175	-1,899,975	-16,063,425	-9,710,610	-35,605,570	-301,028,910	-286,020	-1,048,740	-8,866,620
TOTAL	**4,998,960**	**18,329,520**	**154,967,760**	**111,994,260**	**410,645,620**	**3,471,822,060**	**4,024,155**	**14,755,235**	**124,748,805**

Pacific Northwest
NATIONAL LABORATORY

U.S. DEPARTMENT OF
ENERGY

Proudly Operated by **Battelle** *Since 1965*

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

www.pnnl.gov