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Residential Building Energy Code Field Study

Data Collection & Analysis Methodology

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Acknowledgments

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List of Acronyms

ACH	air changes per hour
CFM	cubic feet per minute
CO2e	carbon dioxide equivalent
DOE	U.S. Department of Energy
EUI	energy use intensity in site kBtu/ft²
FOA	funding opportunity announcement
HERS	home energy rating system
HVAC	heating, ventilation, and air conditioning
ICC	International Code Council
IIQ	insulation installation quality
IECC	International Energy Conservation Code
kBtu/ft²	thousand British thermal units/square foot
kWh	kilowatt hour
MMBtu	million British thermal units
MT	metric tons
Pa	Pascal
PII	personally identifiable information
PNNL	Pacific Northwest National Laboratory
QA	quality assurance
QC	quality control
RESNET	Residential Energy Services Network
SHGC	solar heat gain coefficient

Executive Summary

This document presents a methodology for assessing baseline energy efficiency in new single-family residential buildings and quantifying related savings potential. The approach was developed by the Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE) Building Energy Codes Program with the objective of assisting states as they assess energy efficiency in residential buildings and implementation of their building energy codes, as well as to target areas for improvement through energy-codes and broader energy-efficiency programs. It is also intended to facilitate a consistent and replicable approach to research studies of this type and establish a transparent data set to represent baseline construction practices across U.S. states.

The information presented here encompasses all aspects of conducting a residential field study in single-family homes. It outlines procedures for sampling, data collection and subsequent analysis, and provides guidance on how to implement a successful study, including stakeholder engagement. The document also provides insight based on the experiences of those who have previously implemented the approach.

The field study methodology is based on *key items* identified as having the most significant direct impact on energy savings in single-family households. Efficiency measures are observed as installed in actual homes over a representative sample of households. Collected data is then subject to multiple stages of analysis to identify statistical trends, estimate statewide energy use, and calculate associated measure-level savings. The resulting findings depict baseline construction trends and related energy-efficiency potential for a given state and help identify areas for further intervention, commonly through education and training initiatives.

Highlights of the DOE methodology for single-family residential buildings include:

- Results based on an energy metric and reported at the state level
- A focus on individual energy efficiency measures within new single-family homes
- Data confidentiality built into the experimental design—no identifiable data is shared
- Designed around a single site visit prioritizing key items
- Designed with statistically significant results in mind at the statewide level

The methodology is provided primarily for states and other entities conducting their own studies and will help ensure that results are rigorous and comparable with similar research. This standard approach was tested in eight states that were awarded pilot projects through a competitive bidding process[3] and has subsequently been used in several additional states that funded their own studies. The findings resulting from this methodology will be of value to state energy offices, local government building departments, builders, architects, engineers, contractors, utilities and policy makers. Ideally, states would conduct a study using this methodology every 3-5 years to establish trends in residential single-family new construction and identify areas of change. Ultimately, the results are used to identify household savings opportunities, develop more effective and targeted training programs, create and validate more accurate energy forecasts, inform industry consensus processes, and serve as a baseline for broader energy-efficiency programs and R&D efforts.

[3] See https://eere-exchange.energy.gov/FileContent.aspx?FileID=e6fd3f56-d6cc-4db3-8d26-6b52c4e9c27a. The eight states were Alabama, Arkansas, Georgia, Kentucky, Maryland, North Carolina, Pennsylvania, and Texas

Table of Contents

List of Figures

List of Tables

1 Introduction

This document presents a methodology for assessing baseline energy efficiency in new single-family residential buildings[1] and quantifying related savings potential. The approach was developed by the Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE) Building Energy Codes Program with the objective of assisting states as they assess energy efficiency in single-family residential buildings and implementation of their building energy codes, as well as to target areas for improvement through energy- codes and broader energy-efficiency programs. It is also intended to facilitate a consistent and replicable approach to research studies of this type and establish a transparent data set to represent baseline construction practices across U.S. states.

DOE is directed by statute to participate in all aspects of energy codes – development, adoption and implementation. In recent years, the DOE Building Energy Codes Program has focused its attention on providing assistance for increasing compliance rates with the ultimate goal of ensuring that cost-effective savings are fully realized by U.S. households and businesses. In 2014, this led to the release of a DOE funding opportunity announcement (FOA) which resulted in field studies across eight states[2] using a pilot version of the methodology described in this document. Since then, several additional states have conducted studies based on the DOE methodology, using their own funding, and providing their resulting observations and findings for inclusion in the public data set.

The DOE methodology is based on *key items* – a subset of code requirements identified as having the largest direct impact on residential energy efficiency. Field data for these items, in addition to a broader set of energy efficiency measures and data points, is collected from new homes from a defined geographic area (usually an entire state). A series of analyses then determines:

1. **Measure Statistical Analysis**: Descriptive statistical trends for individual key items;
2. **Measure Savings**: Energy and cost savings potential associated with individual key items based on bringing those items into full compliance with a given baseline (e.g., state energy codes), and;
3. **Statewide Energy Use**: Average energy use in the defined region relative to what would be expected based on the established baseline.

This methodology relies upon an energy metric which differentiates it from earlier approaches that often used a compliance metric (including previous DOE work). Traditional compliance methodologies often yield binary results – either a measure complies or it does not – which ignores both differing levels of compliance (R-0 in a wall is obviously worse in energy terms than R-11, yet if the code requirement is R-15 both are given the same value in a compliance-based approach) and the fact that individual code requirements have very different energy impacts, ranging from zero for administrative items to extremely high for the key items designated here. An energy metric has the further benefit of allowing the results to be compared against different baseline and across geographic regions, which is of significant interest to utilities, government agencies, and others supporting energy-efficiency programs.

The specific energy metric used in this methodology is energy use intensity (EUI). The methodology as originally developed for the 2014 FOA focused on the ability to detect a change in EUI between two discrete samples within the same state – one taken prior to training and education and one after the training and

[1] Defined by the U.S. Census Bureau as fully detached, semi-detached (semi-attached, side-by-side), row houses, duplexes, quadruplexes, and townhomes (any number). In order for attached units to be classified as single-family structures, each unit must be separated by a ground-to-roof wall, have a separate heating system, have individual meters for public utilities, and have no units located above or below.

[2] See https://eere-exchange.energy.gov/FileContent.aspx?FileID=e6fd3f56-d6cc-4db3-8d26-6b52c4e9c27a. The eight states were Alabama, Arkansas, Georgia, Kentucky, Maryland, North Carolina, Pennsylvania, and Texas.

education.[3] The two discrete samples and the training and education were referred to as the three Phases of the pilot study, with Phase I corresponding to the baseline study, Phase II corresponding to the training and education phase, and Phase III corresponding to the post-training study. The term "Phase" used in this context will always be capitalized and usually followed by a Roman numerical to distinguish it from "phase of construction". The term "phase of construction" has its normal meaning in the construction industry, indicating the phase of construction that a home may be under when a particular key item is observable.[4] This methodology is also suitable for use by states conducting baseline studies (i.e., not three-phased studies as conducted by the FOA states).

The methodology is provided primarily for states and other entities conducting their own studies and will help ensure that results are rigorous and comparable with similar research. The resulting findings will be of value to state energy offices, local governments and their building departments, builders and contractors, architects, and engineers, utilities and policymakers. Ideally, states would conduct a study using this methodology every 3-5 years to establish trends in residential single-family new construction and identify areas of change. Ultimately, the results are used to identify household savings opportunities, develop more effective and targeted training programs, create and validate more accurate energy forecasts, inform industry consensus processes, and serve as a baseline for broader energy-efficiency programs and Research and Development (R&D) efforts.

As of the publication of this document, DOE has provided technical assistance to states conducting their own residential energy code field studies. This support has been provided free of charge by way of PNNL, and typically includes sampling development, customized data collection instruments, and analysis. This is intended to assist states with the technical components of the study, as well as to enhance replicability of the methodology and comparability of findings across states.

[3] See the FOA description in the previous footnote, or the description of the pilot studies at https://www.energycodes.gov/compliance/energy-code-field-studies.
[4] See discussion of Key Items in Section 2 and the data collection form in Section 5 for more information on "phase of construction".

2 Key Items

To ensure an affordable and practical methodology, DOE decided to focus data collection efforts on *key items* – energy code measures with the greatest direct impact on residential energy consumption. These form the foundation of the methodology and drive the sampling, data analysis, and resulting savings projections. The key items relied upon in the study are (metric):

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

In identifying the key items, PNNL reviewed all the requirements in the 2009 IECC (ICC 2009) – the most commonly adopted code in the country at the time of this work – and created a draft list consisting of the prescriptive insulation and fenestration requirements in Table 402.1.1 as well as the air leakage, duct leakage and lighting requirements found in other sections of the code. The list was sent out for public review but was ultimately non-controversial and accepted as proposed, being consistent with hundreds of analyses and millions of simulation runs conducted by PNNL and other organizations over the past 30 years. All items on the list have existed in some form in all code versions since 2009, providing ample flexibility for performing comparisons across multiple code editions.

[1] Floor insulation, basement wall insulation, crawlspace wall insulation, and slab insulation were combined into a single category of foundation insulation.

3 Sampling

The methodology requires the project team to define a geographic area for data collection and then collect at least 63 observations of each of the key items (i.e., 63 sets of key items) with the observations distributed across the area to reflect recent construction activity. The derivation of the sample size is further outlined in Appendix A. PNNL is available to create sampling plans for those using the methodology but the information is provided here for those wishing to create their own or looking to understand the mechanics resulting in the state sampling plans.

3.1 State Sampling Plan Development

Census Bureau data[1] is the preferred basis of a state sampling plan if it is available at the county and place[2] level. The plan should be developed using a proportional random sample[3] on the place-level data with the average number of single-family homes constructed in each place over the last three years of data available from the Census Bureau.[4] The sampling plan specifies the number of observations of each key item that must be made in each selected place and must be representative of recent construction activity for the entire state, or portion of the state that has been selected for the project. Step-by-step instructions on how to create a sampling plan from Census Bureau data are provided in Appendix B.

Multiple sample plans can be developed for consideration by the project team and stakeholders. All of these must be statistically valid, but the nature of the random sampling process means that there will be differences between individual plans. The availability of multiple plans allows the project team and affected stakeholders to select one that addresses any specific state circumstances, including political and economic factors, while maintaining scientific validity. The importance of having an accurate, credible plan cannot be overstated as, without it, the validity of the results will be called into question. And while scientific validity should never be sacrificed, it is equally critical to select a sample plan which will produce results that stakeholders find credible. The plan should be discussed in detail during the stakeholder meeting.

If Census Bureau data is not available or is deemed by stakeholders to be non-representative in a particular region, those familiar with construction activity within the study area will need to identify alternative data sources which can be used to develop the sampling plan. Circumstances which may require this include:

1. Census Bureau permit data does not cover the entire state; some counties may not issue building permits and/or not report data to the Census Bureau. A possible solution is to identify permits from another source within the state (e.g., plumbing system permits, HVAC system permits, etc.) that can be used to construct an alternative random sample covering the entire state.[5] Any permit data by place or county (whether from the Census Bureau or not) can be used to generate a sample plan.

2. Census Bureau data covers the entire state, but travel to some remote locations that come out of the random selection process may not be feasible given cost and budget limitations. A possible solution is to substitute a less remote location, ensuring that it is similar in characteristics including climate zone, rural/urban/suburban designation, socioeconomic status, builder types, home type/size, jurisdiction type (incorporated/unincorporated), and other state-specific factors. Substitutions may also be necessary after data collection has begun if conditions in a location do not allow for proper or sufficient data collection.

[1] Available at http://www.census.gov/construction/bps. Select "Building Permits" data. Documentation on obtaining this data may be found at the same link.
[2] "Places" are cities and areas within counties designated in the Census Bureau data. These "places" may or may not correspond to jurisdictions.
[3] A proportional random sample in this project starts with the average number of new home permits for the past three years in each Census Bureau place. Thus, if a state overall had an average of 500 new home permits a year of which Place X had 100 and Place Y had 50, we would expect that, on average, a proportional random selection process would end up with 20% (100/500) of the samples in the plan being allocated to Place X and 10% (50/500) allocated Place Y, proportional to the share of total permits they have.
[4] Time periods other than 3 years can and have been used, as have other data sources. Such decisions should be made by knowledgeable stakeholders to ensure the sample best represents construction trends.
[5] One state that found their eastern portion was not represented in the Census Bureau permit data discovered that they had plumbing permit data for new construction that could be used. Other possible sources include electrical hookup information from utilities.

Any adjustments or substitutions should be discussed with stakeholders in advance and thoroughly documented in a project report along with supporting rationale. Known substitutions, and substitution procedure, should also be discussed as part of the stakeholder meeting. Substitutions should have minimal impacts on the overall sampling plan. If many substitutions are required or a substitution appears necessary for a large population area, a new sample plan should be considered.

3. The state has large sections of unincorporated areas where building permits are issued but no code enforcement is conducted. Given that the unincorporated areas represent a valid part of construction in the state, one solution may be to sample these areas even if it may be harder to identify current construction status of individual homes. Ignoring the unincorporated areas will lead to study results that are not representative of the state.

4. Specific considerations exist within states which need to be addressed in a customized manner. One example would be the start of a large housing development in an area with historically little construction. In this case, using the average construction in each place over the last three years would not provide good representation of the state moving forward.

Table 1 shows the state sampling plan that was used in Maryland as an example. Each number in the target column refers to the minimum number of observations of all key items that need to be collected. All plans will sum to the full number of required key-item samples.

Table 1. Example Sample Plan for the State of Maryland.

Location	Target
Montgomery County Unincorporated Area, Montgomery	5
Howard County, Howard	4
Anne Arundel County Unincorporated Area, Anne Arundel	12
Prince Georges County Unincorporated Area, Prince George	6
Charles County Unincorporated Area, Charles	2
Baltimore County, Baltimore	9
Frederick County Unincorporated Area, Frederick	3
Harford County Unincorporated Area, Harford	4
St. Mary’s County Unincorporated Area, St. Mary's	3
Carroll County, Carroll	1
Calvert County, Calvert	3
Cecil County Unincorporated Area, Cecil	2
Frederick, Frederick	1
Baltimore, Baltimore (city)	2
Easton town, Talbot	1
Worcester County Unincorporated Area, Worcester	1
Wicomico County Unincorporated Area, Wicomico	1
Havre de Grace, Harford	1
Aberdeen, Harford	1
Dorchester County Unincorporated Area, Dorchester	1
TOTAL	**63**

3.2 Local Sampling and Recruitment

The sampling plan developed in Section 3.1 lists the jurisdictions to be included in the study and the number of required sets of observations to be collected from homes in each of those jurisdictions; it does not identify the individual homes to be included in the study. To obtain this information, the project team should contact each jurisdiction listed in the state sampling plan and request a list of all single-family homes permitted under the current code that are currently under construction or have been constructed within the past six months but are not yet occupied.[6]

Permit data is generally publicly available across states though the process and ease of obtaining it varies considerably from state to state. If a “Right to Know” law (or similar) exists in a particular state, requests using the law may present the standard way to obtain permit data. Another tactic which proved useful in some states to facilitate access to this data was to augment the project team with a well-known and recognizable figure, such as a retired building official, who acted as a liaison to the building departments and could help communicate the purpose, goals and logistics of the study.

Code officials have no role in the project other than to provide information on active permits and homes matching the objectives of the study. Not involving them in on-site data collection activities helps ensure builder support for the project as it reduces the perception that the data will be used to inform code officials about non-compliance at a local level. (It should also be noted that a complete picture of ‘compliance’ is deliberately avoided through the study methodology due to the single site visit requirement.) Similarly, excluding owner-occupied homes eliminates the potential for owners to question builders about the data collected. The support and cooperation of builders are critical in accomplishing the data collection effort.

Once the list of all qualified homes is obtained from a jurisdiction it should be sorted randomly to avoid selection bias using the following steps:[7]

1. Enter them into a spreadsheet with all the information for each home in its own row.
2. In an adjacent column, use the random number generator function (in Excel it is “=RAND()”) to create a random number in each row.
3. Copy the results as values into another column. (The RAND() formula re-calculates each time an action is taken in a spreadsheet.)
4. Sort the sheet based on the random number value from smallest to largest.
5. Attempt to contact and then visit the homes in the sorted order. If contact/visit cannot be made, go to the next home on the list until the target number of key item observations for the jurisdiction from the sampling plan is achieved.

Building officials and builders should never be allowed to select specific homes to visit as this will bias the results. However, the project team may use some flexibility in how they address their list of homes. If, as in the hypothetical example below, the team has a list of 20 homes in a jurisdiction and needs to collect at least 3 observations for each of the key items according to the state sampling plan, and notices that 3 of the first 6 homes on the list are in the same neighborhood or section of a jurisdiction, it would be permissible to visit all 3 of these homes “out of order” to save travel costs as the team would certainly end up needing to visit more than those six homes anyway. Note that this example only applies when it is clear that the out-of-order homes would ultimately be visited to achieve the sample plan target number. Project teams do not have the liberty of randomly pulling from the list just to get homes that are in close proximity. Caution should always be applied when going out of order as the credibility of the study is of paramount importance.

[6] The 6-month time period is recommended as homes that were permitted more than 6 months ago may be completed. This is not always the case and local knowledge on the part of the project team will be needed to determine the appropriate time period. If the list of homes permitted in the initial time period is not at least 6 times the number of samples needed in that jurisdiction, then a list should be requested for a longer time period. The 6x multiplier allows for the fact that the project team will not be able to contact all builders on the list, will not be able to gain access to all homes on the list, and may need up to 4 homes to get one complete set of key items.

[7] This assumes the data is in an electronic format. If the list of homes obtained is in a Word file, printout or other format which is difficult to transfer onto a spreadsheet, assign each home a sequential number (either entering it, if it is an electronic file, or handwriting it if a paper file). Then enter these numbers into a spreadsheet and follow Steps 1-3. At the end, there will be a sorted list but it will contain only the number of the house and the random number. The user will need to go back to the original file or printout to get the address, builder and other information about the house.

In terms of scheduling, several teams relied upon tools to help make scheduling and travel more efficient, such as Batchgeo.[8] A team can use this or similar software to enter the randomized list into the tool and get a map. This is also useful in communicating the sampling plan to others, such as at the stakeholder meeting.

3.2.1 Townhomes and Multifamily Buildings

Attached multi-unit buildings, such as duplexes and townhomes, are not the specific focus of the single-family methodology.[9] However, states with a significant population of these building types should consider them in developing their sampling plan. Studies including townhomes or other attached single-family dwellings should specifically inquire if the number of units is available for these buildings. If so, each unit should be placed on a separate line in the spreadsheet noted below so that it has the same probability of being selected as a detached home. In addition, each unit on the spreadsheet should be designated as an end unit or an internal unit (with each building having two end units plus the appropriate number of internal units). For a duplex, for example, both units will be end units; for a triplex there will be two end units and one internal unit; for a quad there will be two end units and two middle units, etc. This is done to ensure a representative mix of end and internal units is available for measures such as air leakage testing and can help inform later analysis.

Studies should ultimately decide whether to include multi-unit buildings within their sample early in the project (e.g., during sampling development), and then deliberately include or exclude them from later data collection. Sampling considerations such as this should also be discussed with informed and affected entities during the stakeholder meeting.

Multifamily buildings are excluded from the single-family methodology. As of the time this document was published, DOE was in the early stages of developing a field study methodology for commercial and multifamily buildings. Updates on these efforts can be found on the DOE Building Energy Codes Program website.[10]

3.3 Sample Plan Substitutions

One issue that commonly arises during the actual data collection phase is that a jurisdiction that is scheduled for sampling has no available homes under construction for data collection. This may happen because there are simply no homes being constructed there, the builders are not willing to let the field teams onsite to collect data, or the local code officials refuse to provide a list of homes currently in the construction process. To address this, substitutions are allowed with these caveats, substitutions must be made:

1. with a jurisdiction with similar socio-economic status. That is, a location in a wealthy suburban location known for very large homes cannot be substituted for a less affluent location known for smaller homes.

2. with a jurisdiction in the same climate zone as requirements often vary by climate zone.

3. with a jurisdiction with a similar level of enforcement.

4. for the minimum required number of observations of all key items, not just some key items. If the field team is unable to find enough ceiling insulation observations in one location, it is not acceptable to find a few ceiling observations in another location to complete the set. A complete set of observations from one location may be substituted only for a complete set of observations from another location.

5. that will be acceptable to the Project Team and all its stakeholders.

[8] https://www.batchgeo.com. There are similar tools available; noted by teams as an example.
[9] Defined as a series of single-family attached units being constructed either simultaneously or sequentially and in contact with each other.
[10] See https://www.energycodes.gov/compliance/energy-code-field-studies

As part of the report generated by PNNL, Project Teams will be required to document any substitutions, including their analysis of why the substitutions meet the criteria above, especially the socioeconomic status criteria.[11]

[11] See Appendix B of the Kentucky Phase I report at https://www.energycodes.gov/sites/default/files/documents/Kentucky_Residential_Field_Study.pdf.

4 Stakeholder Engagement

Studies should include a kickoff meeting of all relevant stakeholders in the state. This meeting should ideally be conducted in person and include any entities interested in or affected by the project. In addition to the project team, this should include (but not be limited to) state officials, code officials, builders, subcontractors, material supply distributors, designers, public interest groups, regulators and utility representatives. Project stakeholders ultimately determine whether the study results will have credibility. It is therefore critical that they be given complete information about the project and have the chance to both ask questions and recommend changes. In a large state, it may be necessary to hold multiple geographically separated meetings to make it more convenient for critical stakeholders to attend. Depending on the outcome, the project team may want to schedule a second meeting to address unresolved issues. The project team should also consider holding meetings throughout the project to keep stakeholders apprised of what is happening with the project. This is especially important if the project team wants help from builders and code officials during the data collection phase of the project.

These meetings are important steps in ensuring adequate levels of stakeholder engagement and buy in. A list of discussion topics that should be covered at the meeting is provided in Appendix C.

5 Data Collection

5.1 Create Data Collection Form

The data collection form should include all state code requirements.[1] While the project focuses on the eight key items identified in Section 2, as much data as possible should be collected to take advantage of the fixed costs of sending teams on site. Beyond the code requirements, additional information needs to be collected for energy simulation modeling during the analysis stage. See Table 7 for a list of these items. Assistance is available from PNNL to create customized data collection forms.

5.2 Access to Homes

The entire data collection effort is predicated on gaining access to homes. This has proven challenging in past studies and project teams are encouraged to use a variety of marketing and networking approaches.

Announcements and letters of support for the study from state and local homebuilder associations, building official associations, state energy offices, utilities and other trusted sources can be extremely valuable in laying the groundwork for successful data collection. Arranging site visits in advance is preferred but there have been successes from simply showing up at a site and explaining the purpose of the study. Some teams found sending a template email or letter explaining the project to local homebuilder associations for them to distribute to local members helped decrease rejection when the field team called individual builders.

The study should always be described and promoted for what it properly is: a baseline data collection effort. Emphasizing that it is not a compliance study and that the data will not be provided to building officials will help make builders more receptive. Note that because the methodology is based on individual items rather than on houses, it precludes drawing conclusions about compliance at the builder or jurisdiction level. This is reinforced by the fact that homes may only be visited once; given the list of key items, this ensures that no house can provide all the needed data and thus can never, by itself, be judged on compliance. All of these points may help reduce objections to the study encountered from stakeholder groups.

An incentive that can be offered to builders is to share their house data with them, particularly the blower door and duct leakage test results. Test results can be shared with the builders upon request, but, in order to maintain confidentiality and objectivity, they should not be shared with code officials unless requested by the builder.

As mentioned, homes are only to be visited once in order to minimize bias and ensure confidentiality. Procedurally, the project team starts by attempting to contact the first house on the randomly sorted list created in Section 3.2 and then continues down the list in order until the minimum number[2] of each of the key items is collected. The number of homes visited in each jurisdiction will therefore always be larger than the minimum number on the sampling plan as not all key items will be observable during a single site visit.

The total number of homes that will need to be visited is not predictable in advance but based on experience in the states that have used the methodology so far, the range is two to four times the sample size or approximately 125 to 250 homes. Given this, the number of qualified homes in a jurisdiction should be at least 6 times the number needed. If this number is not available, refer to the footnote in Section 3.2 to increase the number or consider selecting a different sampling plan that includes a different jurisdiction. Regardless of the total number of homes available, if access cannot be gained to a sufficient number of them to meet the sampling plan target, the sampling plan will need to be revised or a substitute jurisdiction will need to be used.

To minimize the total number of homes visited, homes in a jurisdiction should be visited in order of the random list until the minimum number of observations required in the sampling plan is obtained for one of the key items. After that, homes should be screened during the builder contact process to ensure that they are in the

[1] Sample is available at https://www.energycodes.gov/compliance/residential-energy-code-field-study
[2] Note that the last column of Table 1 shows the minimum number to be collected for each item.

phase of construction where the remaining key items will be observable. This screening process should be repeated every time until the minimum number of observations of one of the remaining items has been collected. To illustrate this approach in a simplified manner, assume that there are only three key items (ceiling insulation, wall insulation, and window SHGC) and the sample plan requires 10 observations of each in a given jurisdiction. After field technicians randomly visit 20 homes, they have observed ceiling insulation in 4 homes, wall insulation in 10 homes and window SHGC results in 7 homes. Having reached their quota for wall insulation, they should begin pre- screening homes to ensure that they only visit those where either ceiling insulation or window SHGC is observable. After visiting another 20 homes they reach 10 observations for SHGC; at this point they would pre-screen to ensure that all remaining homes they visit have ceiling insulation observable. Note that they would continue to collect as much key and non-key item data as possible, which would increase the level of confidence in the results. While deviating somewhat from an ideal random sample, there is no reason to believe that this approach will introduce a systematic bias into the results.

Note that local building departments can be useful in helping to determine the phase of construction for a particular project or providing information that may not be in the permit data. Another idea is to have a "builder expert" on the project team who understands build cycle time, can communicate effectively with the construction trades, and who can analyze the sample data for each jurisdiction and make an educated guess as to whether a site is ready for a field visit.

5.3 Training for Data Collectors

Prior to the start of data collection, systematic training should be provided to all field staff to maximize consistency in the data gathering process. Instructions should include items such as: 1) detailing how the data will be collected (e.g., paper form, electronic form, etc.); 2) emphasizing that only observable information should be recorded (i.e., no assumptions); 3) collecting as much data on the form as possible at each house – not just the key item data; 4) detailing the expected onsite data quality assurance process; and 5) detailing the process and protocols for conducting blower door and duct leakage tests.

Data noted in item 3 can be very informative and valuable to the state, and the project team should take advantage of the opportunity to collect as much of it as possible. DOE's expectation is that a significant amount of this "other" data will be collected.

An onsite data quality assurance process can help reduce analytical questions later. The most common field data problems have been when the field team's responses don't match the questions on the data collection form. For example, a reply of "complies" to the request for the R-value of the insulation of the attic hatch. A simple double check of the data while onsite can help reduce these inconsistency issues.

In addition, project teams have found it very useful (as well as economical) to take many pictures of every home visited to help provide additional documentation and address questions during quality control (QC) and analysis. Saving even one return trip to a site to verify a data question pays for all the time needed to take the photos. Photos might include such things as each elevation of the home, insulation installation quality, and any unusual conditions identified. Emphasizing the use of the comment fields in the data collection form and taking good notes – especially about unusual circumstances – will also minimize the time needed to address QC issues.

Note that only observable information is to be recorded on the data collection form. No assumptions should be made about what will be installed and only installed items should be recorded. As an example, if rolls of batts of R-15 insulation are on the ground inside a house, it should not be assumed that these will be used in the walls as it is possible that they will (incorrectly) be placed in the attic. Similarly, once drywall is up, no assumptions about the R-value of wall insulation should be made. The integrity of the study depends on using only installed observed data. At the same time, every attempt should be made to collect all data specified in the data collection form. Although "non-key" items do not have a minimum number of observations required for the study, many project teams and stakeholders have found this additional data valuable.

Related to entering only observed data is the question of uninsulated envelope assemblies. If a slab-on-grade, roof, floor, or wall has no insulation at the time it is observed by the field team, the field team must decide how to record the observation; for example, the R-0 could be an example of poor compliance or it could be that the insulation has just not been installed yet. If the code requires insulation but there is none and it appears that the assembly is complete, then the "R-0" observation should be made. However, if the field team thinks there is any chance that the assembly may not be complete, then the "R-0" observation should not be recorded.[3]

Another area where the field team should be trained is the identification of outliers. Outliers are discussed later in this methodology under Quality Assurance (QA) and Analysis, but it is the field team that has the first and best opportunity to address them. Outliers are values that fall outside of the expected range of values for an observation. For example, if the ceiling insulation for a home is R-49, it would be unusual to find a ceiling with no insulation (R-0) or a lot of insulation (R-100). Note that R-100 might be possible if the builder were constructing an above code home or a Passive House home. The R-0 value is much more problematic as discussed in the previous paragraph, but it is still an outlier and should be questioned as a real observation. The field team should use the Comment field on the data collection form to flag any values that appear to be outliers.

As part of the data collection effort, project teams are required to conduct a blower door test and duct leakage test on every home where such tests can be conducted, using RESNET protocols.[4] Duct testing should be conducted at the final stage of construction (as opposed to rough-in). For their own purposes, teams may choose to test homes during the rough-in stage as well; however, these values will be used only for informational purposes, and cannot fulfill the key item requirement – a minimum of 63 homes needs to be tested during the final stage of construction. Duct leakage test results are of particular concern related to data outliers. If test results are outside the norm (e.g., inexplicably high), the field team should find another home or duct system to use as the sample. This includes situations where the test equipment is unable to pressurize the ducts. Under no circumstances should a value of 0 be entered as a duct leakage measurement.

5.3.1 Townhomes and Multi-unit Buildings

For multi-unit buildings, data collectors at the site should select a specific unit (and end unit or internal unit matching whatever was selected in the spreadsheet) and all data should be collected from that unit. With the exception of windows and lighting, key items must be observed in the selected unit and may not be substituted from adjacent or nearby units. Observations for windows and lighting may be gathered from another unit within the same multi-unit building, as these items are generally expected to be consistent between units within the same building. Note that such substitute observations must be made within the same building and not from another building in the same complex.[5] The remaining key items, such as insulation, air leakage and duct leakage are all subjective to construction and installation quality issues, so they need to be collected from the designated unit only.

[3] There is a separate tab in the data collection spreadsheet labeled "Zero Insulation Guidance" that provides additional guidance on this topic.
[4] See Chapter 8 of http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf.
[5] A complex is a series of multi-unit buildings co-located in a particular area, but not physically attached to each other. This might be a subdivision or development of townhomes, for example.

6 Quality Control and Assurance

6.1 Data QA/QC

Once the data have been collected, the project team performs a QA check to assure their accuracy. This includes ensuring that all applicable fields are filled in and that values are within reason. The project team should carefully review the data before submittal to PNNL, including looking for any inconsistencies in the collected data as described in the previous section. In addition to the field data, the project team should create a summary table to be included in the final report showing the target number of samples to be collected in each jurisdiction as written in the sampling plan, the actual number of samples collected, and details of any substitutions.

When approximately 20% of the samples have been completed, the project team should send the completed forms to PNNL for review. This allows PNNL an opportunity to identify any potential issues with the data and for the Project Team to rectify those problems prior to the completion of data collection. Forms should also be shared with PNNL at 50% and 75% of completion.

At this point, it is assumed that activities shift to PNNL as few states or contractors have the technical capability or budget to conduct the analyses described in Section 7. After the QA check is completed, the project team supplies the data to PNNL in the form of individual data collection form spreadsheet files for each home. Data collection forms are then loaded by PNNL into the analysis environment.

Once the data is provided to PNNL, it is reviewed to ensure that (common examples):

- Observed foundation insulation values are consistent with the observed dominant foundation types (e.g., if the home is noted to have a crawlspace, there is crawlspace insulation specified);
- Observed foundation insulation values and other key item values are within an acceptable range;[1]
- Insulation installation quality observations for foundations, exterior walls, roofs, and floors is appropriate for the recorded insulation type;
- Heating source is appropriate for the heating system type;
- Buildings with values beyond a reasonable range in each of the data collection items are flagged; and
- Entries for multiple heating or cooling systems are properly listed in the data collection form.

Any identified data issues, including data outliers noted in Training for Data Collectors, are sent to the project team for confirmation or correction.

6.2 Personally-identifiable Information

It is important that no personally identifiable information (PII) be provided to DOE or PNNL. This is information that can be used on its own or with other information to identify, contact, or locate a single person or home. For purposes of this project these include builder name, site address and jurisdiction name. Data confidentiality is critical under the prescribed methodology and project teams should take necessary steps to ensure data is handled appropriately.

To avoid sending PII, the data collection form should include only a coded identification number, or identifier, assigned to each home in this format: two-letter state abbreviation + a unique number assigned by the project team. If issues are found during the data review process, the project team will be contacted with this identifier.

[1] Acceptable ranges for most foundation insulation components are quite broad, as some foundations may have no insulation (R-0) and other foundations could be very well insulated. Questionable observations are cross-checked with the project team.

The field teams are responsible for managing raw data and ensuring that no PII is transmitted to non-authorized parties.

6.3 Public Data

At the conclusion of each state analysis, PNNL will make the raw data collected in the state publicly available in the form of spreadsheets.

7 Data Analysis

The work in this section is assumed to all be completed by PNNL. Once the field data is received and the QA/QC steps are implemented, three analyses occur: statistical, savings and energy, with each one providing a different lens on the data.

The statistical analysis shows the distribution of observations for each key item including the proportion that does not meet the minimum code requirement. This is where savings could be increased by improving compliance levels. The savings analysis focuses solely on the non-compliant observations in the statistical analysis and answers the question, “What energy, cost and emission savings would occur if all key items met the minimum code requirements?” Finally, the energy analysis shifts from the measure level to the whole-house level, comparing the EUI for a simulated population of homes representing the field data to models representing EUI for code minimum homes.

Results from the savings and energy analyses can initially seem conflicting. In the DOE studies referenced in the Introduction, most states showed lower EUIs for the field data homes than the code minimum homes, indicating that states were already doing better than code. At the same time, all states showed significant energy savings potential from increased compliance. This apparent discrepancy exists because the field data has observations that are better than code as well as ones at or below code. The energy analysis incorporates all the field data, effectively allowing better-than-code items to balance out worse-than-code items during the simulations. From a prescriptive energy code perspective, however, all code requirements need to be met; doing better than code on one requirement does not allow you to do worse on another. The savings analyses therefore include only the worse-than-code observations which, by definition, have savings potential. The energy analysis is of more value to those concerned with overall state energy use such as utility planners and state energy offices; the savings analysis helps program managers, building officials and trainers target education and training activities.

7.1 Measure Statistical Analysis

Histograms are created for each key item plotted by climate zone. 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 windows requirement in climate zone 4 is 0.35). Values to the right-hand side of this line are better than code; values to the left-hand side of this line represent areas with savings opportunities. Figure 1 gives an example of the histograms that are provided.

For items that include consideration of insulation installation quality (such as ceiling, wall, floor and basement wall insulation), an additional histogram, as shown in Figure 2 is provided that shows the assembly U-factor, as opposed to the component R-value. The assembly U-factor takes into consideration such things as framing thickness, spacing, and material, as well as siding or roofing, air films, and insulation installation quality (IIQ), and the coexisting cavity and continuous installation components. [1] This histogram provides binned U-factor ranges as the number of individual U-factors calculated in a state may be large. The value of this binned U-factor histogram is that comparison of it and the corresponding R-value histogram identifies whether the issue being observed in the field is related to lack of insulation, installation quality, or both.

Note that in cases where two individual R-value graphs (for cavity and continuous insulation) are provided along with the U-factor graph, the U-factor is usually more informative of the performance of the component

[1] Note that while IIQ is not an explicit requirement in most residential energy codes, it can have a great effect on overall assembly performance. Codes do require all materials, systems, and equipment, including insulation, to be installed according to manufacturer’s instructions. DOE requires collection of this information for use in determining U-factors.

than the two R-value graphs. The reason is that some of the component observations may include both cavity and continuous insulation and not just one or the other. A single cavity or continuous graph cannot capture the performance of a component with both.

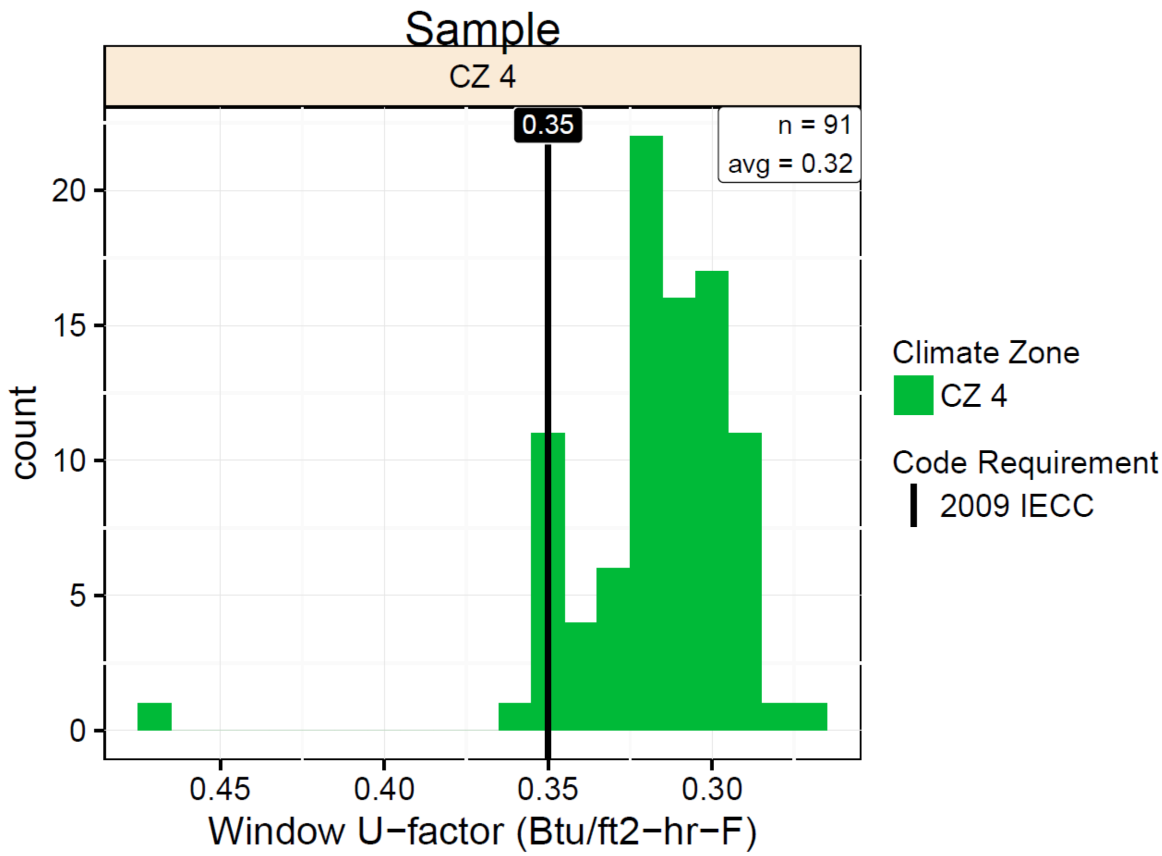

Figure 1. Sample Key Item Graph

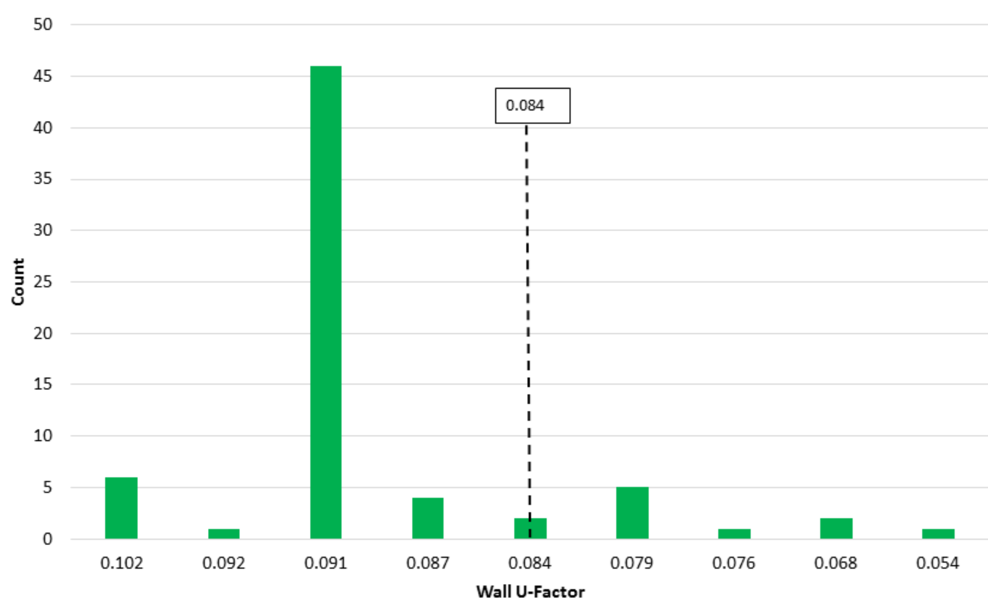

Figure 2. Sample Binned Wall U-Factor Chart

7.2 Measure Savings Analysis

A critical outcome from the field study is to identify the potential energy savings, consumer cost savings, and avoided emissions if all key item observations met the minimum code requirement. This information can be used to encourage funding for programs aimed at increasing compliance and to target education and training activities to ensure maximum impact from such programs. This analysis has three main steps:

1. Data review
2. Model preparation
3. Weighting and results calculation

7.2.1 Data Review

Using the histograms developed in Section 7.1, each key item is first examined to determine those with any non-compliant observed values.[2] Separately for each key item under consideration, only the field observations that do not comply are selected. This is done separately for each climate zone within the state. As an example, assume that 63 observations of envelope leakage were collected in a state where the maximum allowed by code was 7 ACH and 15 (24%) of those observations were not compliant and had the following values:

Table 2. Envelope Air Leakage Observation Example

Observations	Value (ACH)
1	7.2
2	7.4
3	7.5
4	7.5
5	7.9
6	8.1
7	8.1
8	8.3
9	8.3
10	8.3
11	8.4
12	8.6
13	9.7
14	10.8
15	11.2

These would then be aggregated by unique value and weighted as follows:

Table 3. Envelope Air Leakage Observation Weights

Value (ACH50))	Observations	Weight
7.2	1	2%
7.4	1	2%
7.5	2	3%
7.9	1	2%
8.1	2	3%

[2] Originally, a cutoff of 15% non-compliant values for any key item was used. Upon further consideration, this cutoff has been eliminated.

Value (ACH50))	Observations	Weight
8.3	3	5%
8.4	1	2%
8.6	1	2%
9.7	1	2%
10.8	1	2%
11,2	1	2%-
Meets Code	48	76%
Total	**15**	**100%**

7.2.2 Model Preparation

Each value in Table 3 is used to create a building energy model in each climate zone within the state. All components except the measure being evaluated are set at the minimum prescriptive code levels. All variations of heating systems and foundation types observed in the field are included in the analysis similar to the energy analysis described below in Section 7.3, The difference in energy use between the model with the key item non-compliant value and the fully compliant models provides the potential energy savings that would be achieved if the non-compliant observed value in each model was improved to be minimally code compliant.

7.2.3 Weighting and Results Calculation

The energy savings potential in each model of a key item is weighted by the corresponding frequency of each observation (the "Weight" column in the Table 3 example) and then summed to arrive at an average energy savings potential per home for each climate zone. For states with multiple climate zones, potential energy savings for each climate zone are further weighted using construction starts in that zone to obtain the average statewide energy savings potential. Table 4 gives an example for a state with two climate zones where the savings potential per home for a given key item is 85 units (therms or BTUs) in one climate zone and 100 in the other climate zone. A similar approach is used to weight savings from different foundation types in the foundation insulation savings analysis. Savings from each foundation type are weighted using the respective foundation share to calculate aggregated savings at the climate zone and state level.

Table 4. Multiple Climate Zone Weighting Example

Climate Zone	Savings Potential per Home	% of Forecast Housing Starts	Weighted Savings Potential
3a	85	80%	68
4a	100	20%	20
		Weighted Average	**88**

The weighted average savings potential of 88 units is then multiplied by the forecast number of housing starts for the state[3] to give the statewide maximum energy savings potential in MMBtu for that key item. In addition, maximum energy cost savings ($) and associated carbon emissions[4] (MT CO_2e) are calculated using state-specific fuel costs and CO_2 conversion factors. This general process is repeated to calculate the savings associated with each key item having any non-compliant observed values. Summing these together gives the maximum savings potential for the state.[5] Table 5 gives an example of annual potential savings for the significant key items in a state.

[3] The number of previously reported permits, typically based on Census Bureau data, is used as an estimate of the forecast number of housing starts. If not available, PNNL relies on estimates from the project team. For single climate zone states, the link http://www.census.gov/construction/bps/txt/tb2u2014.txt (or updated year version) is useful. For states with multiple climate zones, PNNL processes the Census data into different climate zones by looking at the Censtats annual data for the latest year by county (see https://censtats.census.gov/bldg/bldgprmt.shtml) and assigning each county to a climate zone.
[4] CO2 factors from the EIA are used to convert therms of natural gas and kWh of electricity to MT CO2. These factors are available at: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
[5] This is a theoretical maximum because 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. However, PNNL conducted an analysis comparing savings with and without interaction effects and found that the

Table 5. Statewide Annual Measure-Level Savings

Measure	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Associated Emissions (MT CO2e)
Duct Leakage	14,420	395,063	2,272
Lighting	10,891	385,451	2,408
Envelope Air Leakage	11,207	263,089	1,417
Ext. Wall Insulation	8,022	201,105	1,116
Window SHGC	1,309	54,674	356
TOTAL	**45,849 MMBtu**	**$ 1,299,382**	**7,569 MT CO2e**

Table 6 gives an example of potential cumulative savings for 5 years, 10 years, and 30 years.

Table 6. Five Year, Ten Year, and Thirty Year Cumulative Annual Statewide Savings[6]

Measure	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Associated Emissions (MT CO2e)		
	5yr	10yr	30yr	5yr	10yr	30yr	5yr	10yr	30yr
Duct Leakage	216,300	793,100	6,705,300	5,925,945	21,728,465	183,704,295	34,080	124,960	1,056,480
Lighting	163,365	599,005	5,064,315	5,781,765	21,199,805	179,234,715	36,120	132,440	1,119,720
Envelope Air Leakage	168,105	616,385	5,211,255	3,946,335	14,469,895	122,336,385	21,255	77,935	658,905
Exterior Wall Insulation	120,330	441,210	3,730,230	3,016,575	11,060,775	93,513,825	16,740	61,380	518,940
Window SHGC	19,635	71,995	608,685	820,110	3,007,070	25,423,410	5,340	19,580	165,540
TOTAL	**687,735**	**2,521,695**	**21,319,785**	**19,490,730**	**71,466,010**	**604,212,630**	**113,535**	**416,295**	**3,519,585**

7.3 Statewide Energy Analysis

The energy analysis leverages the statistical analysis results to model an average statewide EUI in a typical home. 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 full set of inputs to generate reliable results. To address this challenge, a series of over 1,500 "pseudo home" models for each climate zone in a state is created using a Monte Carlo simulation.[7] The pseudo homes encompass most of the possible combinations of key items values in proportion to the distributions found in the observed field data. In aggregate, they provide a statistical representation of a state's population of newly constructed homes.

These combinations are made up of all the observations from a state – not just those observed in an individual climate zone. Thus, if a state encompasses climate zones 3, 4, and 5, observations are pooled across all three climate zones and the Monte Carlo simulation is applied to the pooled observations. This implies that it is possible to see a pseudo home for climate zone 3 that includes multiple observations taken from climate zone 5

relative impact of such interactions is quite small and can be ignored in the assessment of potential energy savings, so long as most of the other building components comply with the code.

[6] The savings here are larger than the simple sum of annual savings because savings from previous homes continue and the savings for the new homes are added on to it. After five years, for example, there are five years' worth of savings from houses built in the first year, four years of savings from houses built in the second year, etc.

[7] https://en.wikipedia.org/wiki/Monte_Carlo_method. This particular application of the Monte Carlo methods involves the creation of the "pseudo home" models from random draws from the probability distributions for the key items.

where requirements may be more stringent. This pooling was implemented to address the fact that there may not be enough observations in all climate zones to do a full analysis. However, the pooling also leads to a potential skewing of the results of the EUI calculation if the requirements in the applicable climate zones are significantly different or if one climate zone is dominant in the state.

In addition to the key items, several additional (i.e., non-key items) listed in Table 7 are used to provide supplemental information or modifiers needed for the pseudo home models.

Table 7. Non-Key Data Items Contributing to Energy Modeling and Analysis

Non-Key Data Collection Items	Use
Percent Supply Duct in conditioned space, Percent Return Duct in conditioned space	Re-sets duct leakage to 0 in the simulation if both supply and return duct are entirely inside the conditioned space
Predominant Heating Source, Heating System Type	Determines the percentage of pseudo home models that have each of the heating system types observed in the collected data
Predominant Foundation, Is Basement Conditioned, Is Crawlspace Vented	Determines the percentage of pseudo home models that have each of the foundation types observed in the collected data

Each of the 1,500 pseudo homes in a climate zone is run in each of the 20 prototype model variations found in the observed data for a climate zone. The 20 possible variations reflect the unique combinations of the four most common heating systems (heat pump, electric resistance, gas furnace, and oil furnace) and five most common foundation types (heated basement, unheated basement, slab-on-grade, vented crawlspace, and unvented crawlspace). Assuming the observed data contains all five foundation types and all four heating systems, there would be 30,000 model runs completed for each climate zone (1,500 pseudo homes x 5 foundation types x 4 heating system types).

The 1,500 models developed from the pseudo homes represent the "as-built" homes in the climate zone which then need to be compared to the code baseline. To do this, "code-compliant" versions of the 20 prototype model variations are developed which just meet the minimum prescriptive code requirement for each of the key items. For a state with all five foundation types and all four heating systems observed, there are 20 code-compliant models created for each climate zone in the state.

7.3.1 Townhomes and Multi-unit Buildings

The analysis was conducted using the PNNL detached single-family prototype building model which represents the most dominant configuration of homes across the country. However, two states included in the pilot study exhibited a large population of townhomes (MD and PA). PNNL investigated the effect of including townhomes within the state's analysis and noted a few key differences relative to states without a significant multi-unit population. Mainly, the EUI for townhomes tends to be lower than that for detached single-family homes because townhomes typically have lower exterior wall areas and lower window areas—both resulting in lower heat transfer through the building envelope. The overall complexity of the analysis necessitated combining the observations from the townhomes with those from detached single-family homes. The impact of this simplification on the results is that the statewide mean EUI and the measure-level savings in the affected states may be overstated. However, delta EUIs between the Phase I statewide mean and the baseline code-compliant EUI would likely remain unchanged because any change are expected to affect both the baseline and the observed EUIs similarly.

7.3.2 Model Adjustments

Two model adjustments are made to the models prior to running the energy simulations. These include adjusting for insulation installation quality and duct leakage. Both are needed to enhance the simulation and ensure that the influence of these measures is accommodated and accounted for in the analysis.

7.3.2.1 Insulation Installation Quality (IIQ)

At the start of the project, IIQ was noted as a particular concern among project teams and stakeholders as it plays an important role in the energy performance of envelope assemblies. However, insulation installation is not a requirement in the model energy codes and is not a key item by itself. Data on cavity IIQ was collected in the field and used in the analyses to modify the energy contribution from ceiling, wall and foundation insulation. It is a separate input to the model, implemented according to the approach employed in the RESNET home energy rating system (HERS) rating software[8] as follows:

1. **Grade I**: 100% of the cavity area is assumed to be insulated to the observed R-value insulation;
2. **Grade II**: 98% of the cavity area is assumed to be insulated to the observed R-value and 2% is assumed to be uninsulated.
3. **Grade III**: 95% of the cavity area is assumed to be insulated to the observed R-value and 5% is assumed to be uninsulated.

The empty cavity areas are assumed to have cavity air spaces with R-values selected based on ASHRAE Standard 90.1-2013 (ASHRAE 2013).[9] A sample calculation for R-13 exterior wall cavity insulation is shown below in Table 8. As shown, even a 2% empty cavity (Grade II) can impact the R-value of the wall assembly up to 12%, while a Grade III IIQ can degrade the assembly R-value by as much as 25%.

Table 8. Impact of IIQ on the Effective R-value of the Framing-Insulation Layer of Walls

	Fraction Framing	Fraction Cavity	Fraction Empty	Conductivity (Btu-in/hr-ft^2- F)	Thickness (inches)	R-value (hr-ft^2- F/Btu)
R-13 Grade I	25.00%	75.00%	0.00%	0.402	3.500	8.709
R-13 Grade II	25.00%	73.50%	1.50%	0.456	3.500	7.683
R-13 Grade III	25.00%	71.25%	3.75%	0.536	3.500	6.529

7.3.2.2 Duct Leakage

EnergyPlus has the capability of simulating entire duct distribution systems including the impact of heat transfer through the ducts and duct leakage through its specially defined “Airflownetwork” module. However, integrating this module in a whole-building simulation is complex and made even more difficult by the large number of models of interest in this study. Given these challenges, the impact of duct leakage is calculated separately and then applied in the EUI analysis through post-processing (Mendon et al. 2013). The following steps are used separately for each climate zone to factor duct leakage values into the analytical results:

1. Using the EnergyPlus Airflownetwork module, a set of models is created to represent each unique duct leakage value observed in the field, while maintaining all other building components at the minimum code-compliant level. As an example, if 40 duct leakage values were collected and 30 were unique values, then 30 models are created, with each one identical except for the duct leakage value. An additional model is created with a duct leakage value equal to the code requirement. These models are further expanded to include all combinations of heating systems and foundation types observed in the field.
2. Simulations are run for all of the models created in (1) to obtain EUIs. These EUIs are then aggregated across the foundation types and heating systems to get the EUI of the code-compliant model and the models for each of the duct leakage values (30 in the example).

[8] See http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf
[9] See Tables A9.4.1.4-1 and A9.4.1.4-2 of ASHRAE Standard 90.1-2013

3. An EUI adjustment factor is created for each unique duct leakage value which is the ratio of the EUI of the model of each unique duct leakage value to the EUI of the code-compliant model. This set of percentage adjustment factors serves as a lookup table that consists of pairs (30 in the example) of unique duct leakage value and the percentages. These factors indicate the impact of duct leakage on the whole-building EUI.

4. Together with all other key items, a field observed duct leakage value is assigned to each of the pseudo models during the Montel Carlo process. Adjustment factors calculated in (3) are applied to the EUI of each pseudo home in the main analysis by matching the field observed duct leakage value to the adjustment factor from the lookup table in (3). This adjustment gives the EUI for each building after accounting for duct leakage losses.

7.3.3 Energy Simulation and Calculation of EUIs

PNNL uses EnergyPlus to conduct the energy simulation and calculate the EUI. The EUI includes only regulated end uses: heating, cooling, lighting and domestic hot water.[10] Simulation is conducted on all the code-compliant models and all the pseudo home models. Results are aggregated to one average EUI per climate zone using the following steps:

1. Starting with 30,000 models (1,500 draws x 5 foundation types x 4 heating system types), models are binned into unique foundation type/heating system type combinations. For each model, two weights are assigned – one weight for the foundation type and another for the heating system type. The weights represent the percentage of each found in the field data. If gas furnaces were found in 40% of the homes, a model with a gas furnace would have a weight of .4 for heating type.

2. The weights are multiplied by the EUI in each of the 30,000 models to give a single, weighted, unadjusted EUI for each of the 1,500 pseudo homes.

3. The duct leakage adjustment calculated in Section 8.3.1.2 is applied to the unadjusted EUI for each of the 1,500 pseudo homes to calculate the final EUI of each pseudo home.

4. The average EUI for the climate zone is calculated by averaging the EUIs for each of the 1,500 pseudo homes.

For states with a single climate zone, the results from the climate zone are the results for the state. For states with multiple climate zones, an average statewide EUI is calculated based on the individual climate zone EUI in the state weighted by the percentage of homes built in each climate zone. The total number of homes built in a state is based on the annual number of permits from the Census Bureau.[11] The number of permits by climate zone is determined using the county- or location-level data from the Census Bureau, assigning each county or place to a climate zone, then summing the number of permits issued in a climate zone.

7.3.4 Climate Zone Specifics

Each climate zone in the state has the same number of EnergyPlus simulations performed because this more accurately represents the extremes that could exist in the distribution of EUI values shown in the histograms. However, for a state with multiple climate zones, it is typical for one climate zone to contain a much larger proportion of the new construction. To show the combined EUI histogram distribution, the same construction weights across climate zones that establish the state average EUI are used. Thus, if a state has two climate zones where one accounted for 80% of new construction and the other accounted for 20%, then the individual histogram bins for each zone would be scaled by 0.8 and 0.2, respectively. An example statewide EUI result

[10] Ventilation is assumed to be present in all new single-family homes, regardless of the code in place, with an assumption of 60 CFM exhaust fans. The 60 CFM value is calculated from the conditioned floor area and number of bedrooms in DOE's single-family residential prototype. This assumption is consistent with DOE's residential codes cost-effectiveness analyses and methodology. The impact of additional infiltration (due to balancing the 60 CFM exhaust) is accounted for in the heating and cooling loads.

[11] See https://www.census.gov/construction/bps/txt/tb2u2014.txt and https://www.census.gov/construction/bps/txt/tb2u2015.txt

shows this in Figure 3. It includes the prescriptive code minimum EUI and the observed EUI. This example has two climate zones, 2A and 3A, and illustrates that overall in this state, a typical home uses more energy than a code-compliant home.

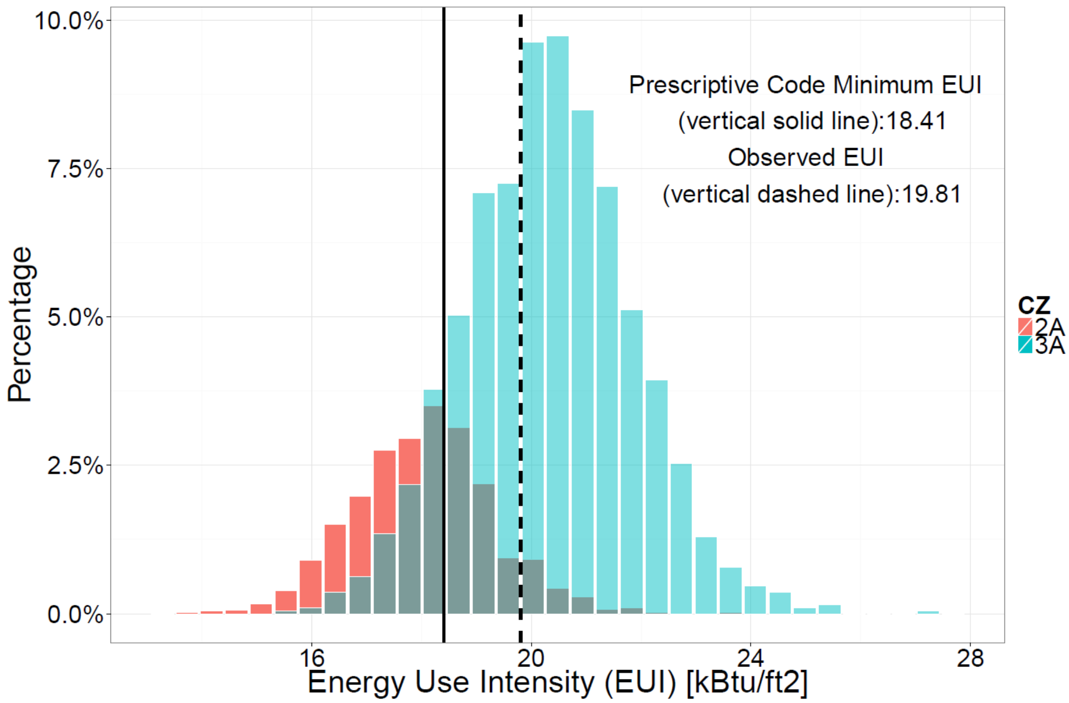

Figure 3. Modeled Distribution of Regulated EUI (kBtu/ft2/year) in Example State

7.3.5 Comparing EUI Across Phases

A key feature of this methodology is the comparison of the EUI for the state between Phase I and Phase III. This comparison is discussed in the Introduction and was in fact one of the main drivers of the development of this methodology. The calculation of a statistically significant difference in EUI is discussed in Appendix A. Note that when doing a comparison of Phase I and Phase III analyses, as was done for the original states that used this methodology, it is imperative that items such as the predominant heating source and heating system type, and the predominant foundation types, along with the split of permitted homes between climate zones be kept constant. If not, the EUI difference calculated may reflect the difference in these weighting assumptions rather than the difference in observations. Therefore, the types and shares of predominant heating systems, the types and shares of the predominant foundations, and the split of climate zones of Phase I were kept constant for Phase III.

7.4 Non-Key Item Statistical Analysis

In parallel with the key item statistical analysis, the savings analysis and the energy analysis, PNNL conducts a simple analysis of the non-key items. While some of the non-key items are not regulated in the energy code, they still provide valuable information to the state. A variety of simple means and counts are provided in the report, with tables showing distributions where applicable. Non-key items are not currently subject to the detailed initial QA directed at the key items, but PNNL may ask the project team to confirm some non-key item observations if outliers or other problems are found.

8 Conclusion

DOE encourages states, utilities and other entities to leverage this methodology in assessing baseline energy efficiency in single-family residential buildings. Through the prescribed approach, studies can generate informative data sets surrounding implementation of state codes and broader energy-efficiency programs.

Findings can be used to quantify related savings potential and estimate statewide energy use, as well as to target areas for improvement with a focus on the most cost-effective efficiency measures. Ideally, states would conduct a study using this methodology every 3-5 years to establish baseline trends in residential single-family new construction and identify changes over time.

The methodology is provided primarily for states and other entities conducting their own studies and will help ensure that results are rigorous and comparable with similar research. The findings resulting from this methodology will be of value to state energy offices, local government building departments, builders, utilities and policy makers. Ultimately, the results are used to identify household savings opportunities, develop more effective and targeted training programs, create and validate more accurate energy forecasts, inform industry consensus processes, and serve as a baseline for broader energy-efficiency programs and R&D efforts.

As of the publication of this document, DOE has provided technical assistance to states conducting residential field studies. This support has been provided free of charge by way of PNNL, and typically includes sampling development, customized data collection instruments, and technical analysis of collected data. This is intended to assist states with the technical components of the study, as well as to facilitate a consistent and replicable approach to identifying baseline construction practices across U.S. states.

DOE will continue to update this document over time based on the findings and experiences of ongoing studies utilizing the methodology. As of when this updated document was published, several state studies were active and will continue to generate additional data on baseline residential construction trends. The most recent information on these studies and related research efforts will be available in an ongoing basis on the DOE Building Energy Codes Program website, www.energycodes.gov.

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Appendix A – Sample Size Determination

The original DOE pilot studies included three phases; (1) an initial baseline field study; (2) an intervention of education and training programs, and (3) a post-study to assess whether a change in statewide energy use could be detected, as resulting from the education and training programs. A goal of the original pilot program was to enable the comparison of the pre-intervention baseline study to those of a later post- intervention study with 90% statistical confidence that any differences found between studies would be within 10% of their true population values.[1] The sample size selected for the studies was consistent with this goal.

PNNL used the following process to determine the required sample size:

1. **Estimate the distribution of expected observations for each key item in each climate zone using a Delphi process**.[2] For "wall cavity insulation", for example, if the code requirement is R-20, the experts expected that there would be a strong tendency for most of the observations to cluster tightly around R-20, but with many observations of the commonly available R-19 as well. Some observations would be expected for other similar, common levels of wall insulation such as R-15 or R-11, but it was considered very unlikely that there would be no insulation (R-0), or lots of insulation (R-25, R-30, etc.). As an example, wall insulation in Climate Zone 5 was assigned the distribution in Table A.1.

   Table A.1. Wall Insulation Distribution Example

Value	Expected Distribution
R-0	0%
R-5	0%
R-11	2.5%
R-13	12.5%
R-15	5%
R-19	35%
R-20	37.5%
R-21	7.5%
>R-21	0%

   This process was repeated for each key item/climate zone combination.

2. **Model the expected impact of individual key items.** Separately model each expected value determined through the Delphi process using PNNL's residential single-family prototype building model[3] and EnergyPlus™ simulation software.[4] Keep all other inputs[5] of the models at the 2009 IECC minimum required levels. Calculate the difference in EUI (energy use intensity = kBtu/ft^2/year) between each of these model runs and separate runs representing the code-minimum prototype.

3. **Apply statistical sampling to create an energy distribution**. Take the results from Step 2 and use them to apply a statistical sampling method known as "bootstrapping"[6] to create an energy-based distribution for each key item that is proportional to the weights derived in the Delphi process. Figure A.1 shows the standard deviation results from the bootstrap estimation for a whole-building energy metric and the EUI

[1] The eight states selected by DOE for its pilot study (i.e., FOA mentioned in the Introduction) were required to complete a three-phase project consisting of a baseline field data collection (Phase I), market interventions (Phase II) and a post-intervention field data collection (Phase III).
[2] A Delphi process is an estimation technique commonly used in the absence of measured or observed data. A team of experts on a particular topic is asked to estimate the values that should be used and their estimates are pooled. In this case, the experts were asked to estimate the distribution (value and percent of likely observations, by climate zone) for each of the key items. The Delphi process was conducted in August 2014 prior to the start of any field data collection. Three senior PNNL researchers familiar with energy codes and building performance contributed to the Delphi process.
[3] Available at http://www.energycodes.gov/development/residential/iecc_models.
[4] See https://energyplus.net
[5] Duct leakage was not included in the sample size analysis due to energy simulation software limitations and computational constraints.
[6] http://statistics.about.com/od/Applications/a/What-Is-Bootstrapping.htm

values associated with envelope tightness, window SHGC, window U-factor, and exterior wall insulation. The estimates of whole-building and envelope tightness EUI difference are consistent for each state and similar across seven of the eight original FOA study states. For all study states except Pennsylvania, a standard deviation for whole-building EUI of 2.8 (grey vertical line in Figure A.1) was assumed and shifts of at least 1.25 kBtu/ft^2 would need to be detected between the pre- and post-studies. Using the sample size equation below with a type I error (α) of 0.05 and a type II error (β) of 0.2 as input into a standard normal function, *Z*, the proposed sample size is 63.[7]

4. **Calculate standard deviations.** Use Step 3 results to calculate a standard deviation for each item. Insert in this standard equation to determine minimum sample size at the desired 90% confidence level.

$$m = n = \frac{2s^2\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2}{\Delta^2} + 0.25Z_{1-\alpha}^2$$

where

m and n = sample size
s = the standard deviation of the EUI associated with each key item. For this study, a value of 2.8 corresponding to the standard deviation of the EUI associated with ACH50 was used.
Z = the standard normal function, with Z evaluated at 1-α and 1-β. The Z function may be calculated in EXCEL using the NORMSINV command.
α = the allowable Type 1 error or significance level. For this study, a value of 0.05 was used.
β = the allowable Type 2 error or power. For this study, a value of 0.2 was used.
Δ = the difference in whole-building EUI to be detected between Phase I and Phase III.

For this study, a value of 1.25 kBtu/ft^2 was used. Due to the higher estimates for the standard deviations in Pennsylvania, the recommended sample size of 63 will only have the power to detect differences of 2.35 kBtu/ft^2 in Pennsylvania as opposed to the 1.25 kBtu/ft^2 detectable differences for the other seven states.

[7] http://vsp.pnnl.gov/help/Vsample/Design_2_Sample_T_Test.htm

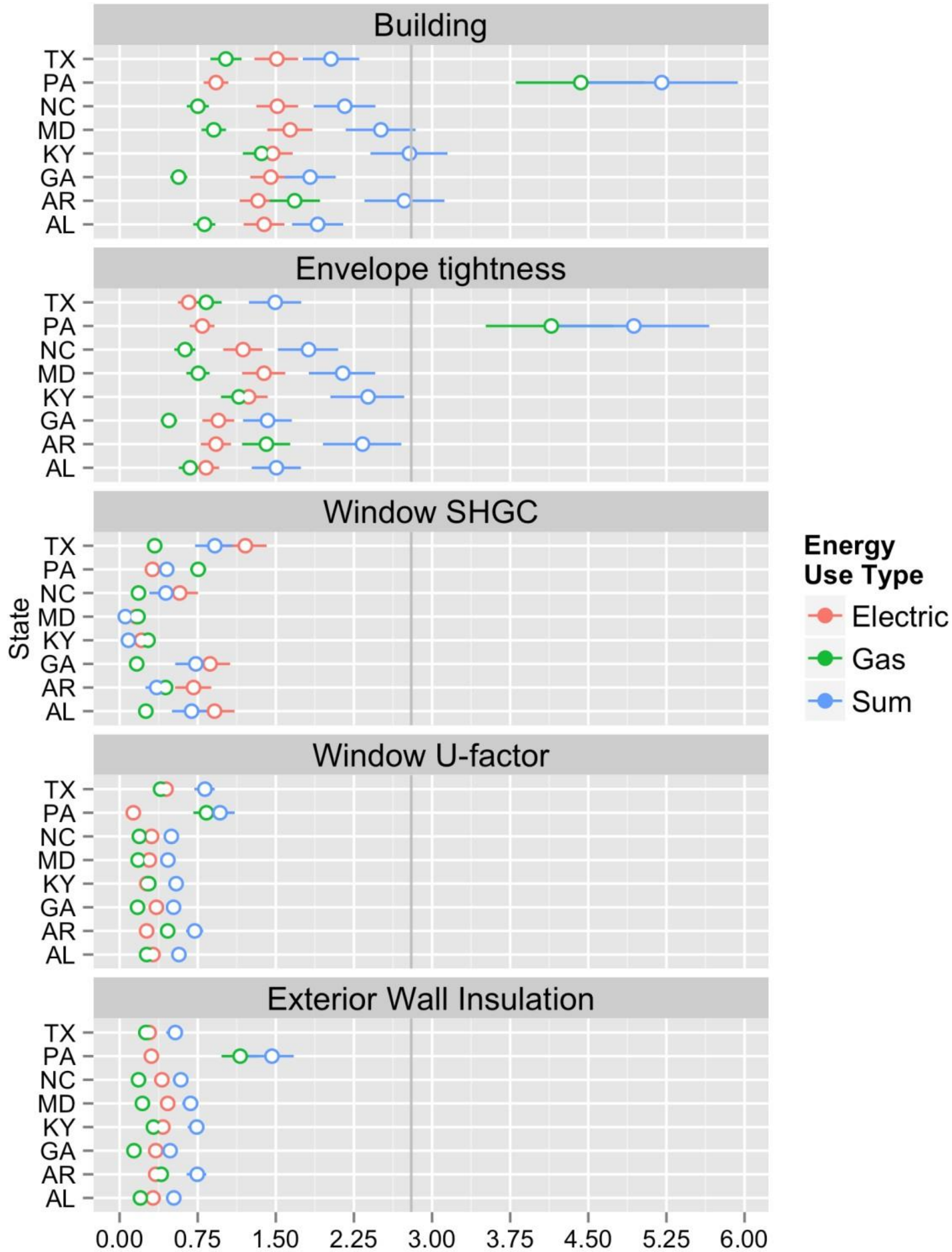

Figure A.1. Summary of the Bootstrap Estimates from the Simulation Study for the Eight States. Resulting potential standard deviation values are shown on the x-axis.

Figure A.2 depicts sample size sensitivity to the desired detectable difference using two different standard deviation assumptions. The grey horizontal line shows the recommended sample size.

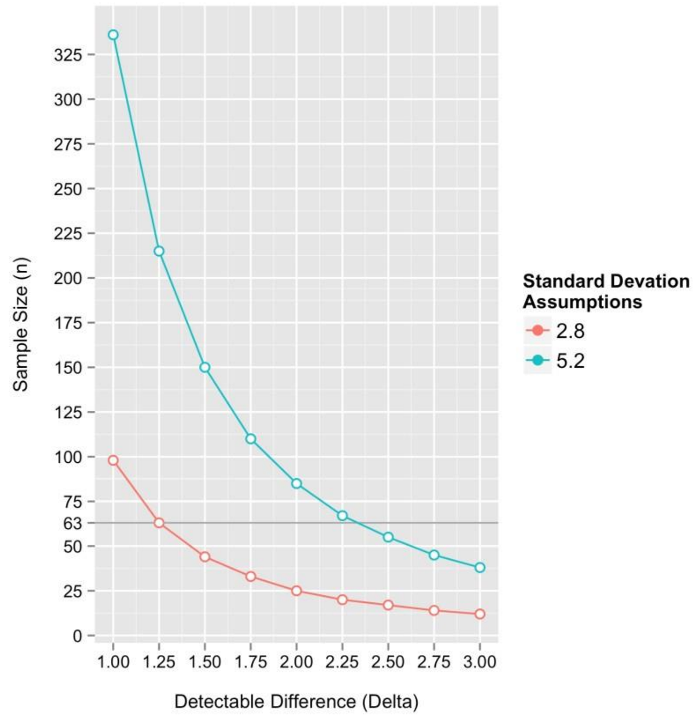

Figure A.2. Sample Size Sensitivity Plot using Two Different Standard Deviation Assumptions

5. **Identify minimum sample size.** The key item with the highest standard deviation, envelope tightness (ACH50), was used to establish a **minimum sample size of 63 observations for all key items**. While this may have resulted in oversampling for some of the other key items, it was considered an appropriately conservative approach given the inherent uncertainty in the Delphi process. Requiring the same sample size for all key items also simplified the instructions to the project teams.

Appendix B – Creating a Sampling Plan from Census Bureau Data

B.1. State-Level Sample

Follow the steps below to create a state-level sample plan based on three years of U.S. Census Bureau permit data. In typical circumstances, the three-year time frame was judged adequate to smooth out any single year increases or decreases in permit applications, such as those associated with a new subdivision in a location.[1] This protocol assumes that all jurisdictions in a state issue permits and report them to the Census Bureau. If that is not true, review Section 3.1 for discussion of exceptions and possible alternative approaches. In all cases, the permit data downloaded from the Census Bureau and any sample plan generated from that data should be checked to ensure that they make sense to knowledgeable people.[2]

Data is available from the Census Bureau at https://www.census.gov/construction/bps/. Permits are available by place, county, metropolitan statistical area, and state. Permits are also available at the annual or monthly level. In the DOE studies, the following data were most typically used:

- Annual permit data by place for sample plans
- Annual permit data by county to determine the climate zone split of permits within a state.

It should also be noted that the term "place" is used to designate the lowest level of government issuing building permits. In some states, a "place" may be a county, thus the "place" and county data for that location is identical. "Place" may also include "unincorporated areas of a county" as well, which might indicate that the county must be contacted for a list of homes available for sampling.

Annual Census Bureau data by place is available in four separate region files by year – one file for the South, one for the Northeast, one for the Midwest, and one for the West. The states that are included in each are defined in the file "States by Region, Division" under "Select Documentation for Codes" on the "Customer Information, Sample Files, and Documentation" link on the main permits webpage.[3] For example, if three years of data (2013, 2014, and 2015) for Alabama are needed, the files for the South Region for those years should be downloaded, because Alabama is in the South Region. The files are typically named "<2 digit region><4 digit year>c.txt".[4] These comma delimited text files must be imported into a spreadsheet or database for processing.[5]

The data files downloaded include a lot of data that is not used in a sample plan. The data available from the Census Bureau includes two distinct sets of information for four distinct types of residential buildings. The two distinct sets are "reported data" and "imputed data", with the imputed data being calculated by the Census Bureau to fill in holes that occur when jurisdictions do not report (for whatever reason).[6] The sample plans developed for the DOE study mostly used the imputed data, although at least one state chose to use reported data. Given that the imputed data is the Census Bureau's "best guess at what the right answer is", these values should probably be used unless there is a significant reason to use just the reported data. Differences between

[1] The project teams should consider if a three-year average is appropriate for their state.
[2] One state found that the entire eastern portion of their state was not represented in the permit data or sample plan. This was only apparent when the sample plan was plotted on a map of the state.
[3] Direct link at https://www.census.gov/construction/bps/sample.html.
[4] The complete Census Bureau place level file documentation is available at https://www.census.gov/construction/bps/sample/placeasc.pdf. There are many other data files in the regional directories.
[5] Instructions for importing text files into EXCEL are available at https://www.census.gov/construction/bps/pdf/importingpermitsfilestomicrosoftexcel.pdf.
[6] Information on how and why the Census Bureau imputes data may be found at https://www.census.gov/construction/bps/sample/impute.pdf.

imputed and reported permit totals for a state may be 10% (with imputed data always larger), but differences may be much larger for individual jurisdictions.

The four distinct types of residential buildings for which permits are collected are single family, two-family, 3 or 4 family, and 5 or more family units. For each of these four types, information on the number of buildings, number of units, and the value of the buildings permitted is provided. For this methodology only the single-family data and number of buildings for single family units are used.

B.2. Processing the Permit Data Prior to Sample Plan Development

There are multiple steps that must be taken to process the downloaded Census Bureau data before creating a sample plan. Some of these steps will be needed for every state sample plan, while other steps may only be needed for some states.

- **Step 1:** Assemble all the data needed in a single spreadsheet. The place data downloaded from the Census Bureau is for individual years for regions of the United States. Data for the state of interest should be split out into a separate tab for each year, and then the state tabs for each year combined into a single new spreadsheet that will serve as the basis of the state sample plan. To split out the regional data by state, filters can be applied to the state Federal Information Processing Standard (FIPS) code column in the data file.[7] The regional data file can be filtered to show only a particular state and then that data copied to new tab in a spreadsheet for further processing.

- **Step 2:** Convert the state and county codes to actual state and county names. The Census Bureau provides a FIPS state code and FIPS county code file in the previously discussed documentation portion of the Census Bureau website.[8] These files are .CSV files that may be opened directly by a spreadsheet program and saved as separate tabs in a data file. A function such as Excel's VLOOKUP function can be used to convert the FIPS state and county codes to state and county names for future use.

- **Step 3:** Align or synchronize all of the downloaded data. Data from individual years may vary in terms of the actual number of places listed as reporting permit data. One major change occurred in 2015 when the Census Bureau changed what is called the "Building permits universe" to sample a slightly different set of permit issuing jurisdictions. Thus, there may some jurisdictions that were included in data prior to 2014 that are not in the 2014 data and vice versa.[9] Many of the jurisdictions that appear or disappear over time are smaller jurisdictions without much permit activity and these jurisdictions are unlikely to show in a random sample that is focused on the jurisdictions issuing 90% of the permit in a state (as is done in the DOE study). However, to ensure that data is aligned for averaging, it may be necessary to insert blank rows in one or more of the annual files downloaded to make all the place names align. One way to do this is to insert a blank row, highlight the row in a distinctive color, and then note the place name for the blank row in the appropriate column. It is important that the values in this row be blank and not zero (0). The AVERAGE function ignores blank spaces so the average value calculated for places that have only two annual observations rather than three will still be a legitimate value. If zeroes are added, the average value will be artificially lowered. In addition, there is no justification that the value for the missing place is zero – it is simply not included and could have any value.

Once the average over the desired period is obtained for each place, the data should be copied to a separate tab and sorted in descending order by number of permits. The data downloaded from the Census Bureau is in

[7] State FIPS codes are also defined in the FIPS State Codes file available in the documentation link previously described. See next paragraph for converting FIPS codes to actual names.

[8] It should be noted that 4 states in the US – Maryland, Virginia, Missouri, and Nevada have what are called "independent cities" that are part of the state but are not in a county in the state. These places are identified with special county codes in the Census Bureau files. See https://en.wikipedia.org/wiki/Independent_city_(United_States) for more information.

[9] See https://www.census.gov/construction/bps/how_the_data_are_collected/ for more discussion on the building permits universe and its changes over time.

alphabetical order by place name, but for development of a sample plan having the data sorted by decreasing number of permits is useful.[10] This sorted list of places, the associated counties, and associated average number of permits will form the input to the sample plan.

B.3. Generating the Sample Plans

The objective of the sample plan is to identify the 63 places in a state that must provide a complete set of key item observations. The input to the sample plan is the list of places, their associated counties, and associated average annual permits. The key step in developing a random list of places is to associate each expected annual permit in a state with a random number and then draw 63 random numbers and identify the places that correspond to those numbers. Here is the approach:

1. Sum up the average annual permits for the state (simply the sum of all the average annual permits for each place). This value can be placed in the same column as the average annual number of permits but in the first row below the list of places.

2. Divide the number of average annual permits for each state by the total number of permits calculated in (1). Since the list of places is sorted in descending order of average annual permits, the places at the top of the list will have the largest percentage of permits. This calculation should be done in a separate column.

3. Sum up the percentage of permits down the list to generate a cumulative average annual permit percentage. The sum of the percentage for the first row is simply the percentage calculated in (2). The sum of the percentage for the second row is the sum of the percentages for rows 1 and 2 calculated in (2). This should be done in a separate column.

4. Identify the row in the list of places that represents approximately 90% of the cumulative average annual permits. One of the goals of the DOE study was to sample approximately 90% of the new construction in a state. Cutting off the sample at 90% implies that the field teams will not be sent to places that have relatively few permits per year, as those places may have few or no homes available for sampling. The actual number of permits issued in the place that corresponds to a cumulative average annual permit of about 90% will vary depending on how permits are distributed in the state. If the state has a "long tail" of permits, with many jurisdictions having a small number of permits, it may be necessary to visit some smaller jurisdictions. If the permits are more concentrated in several major jurisdictions, then achieving 90% coverage may mean only visiting those larger jurisdictions. Generally, the aim is to make sure that any place that field teams are sent will have at least 20 annual permits to ensure sufficient homes are available. In some states, the 90% value can be increased to 92% or 95% to achieve greater coverage, but this results in the field teams visiting additional smaller jurisdictions with the added expense associated with those visits. Achieving the right balance between the desired coverage level and the availability of homes to sample is critical. If there is a total of 1,000 cumulative average annual permits in a state, then 90% coverage indicates the row where 900 cumulative average annual permits exist (call this "Place X in County Y").

5. Insert a separate column that starts with the number "1" corresponding to the first place and with an equation summing up the cumulative starts from place 1 to the place in question. Thus, for place 2, the equation would be the sum of the starts for place 1 plus the starts for place 2. This number should be the same as the cumulative starts calculated above, but is offset one row. This column will provide a unique index number for each permit issued by a place.

[10] This sorting step is not strictly mandatory, but it is how all existing sample plans have been developed, and it does focus attention on the jurisdictions with the largest numbers of permits that are most likely to be sampled.

6. Insert a separate column that contains the concatenated place name and county name. This column will be used to determine where the sample is to be taken.

7. Define a table with four columns and 63 rows.

   A. In the first column, fill the cells with the numbers 1 to 63.

   B. In the second column, insert an equation to generate a random number using a spreadsheet function such as Excel's RND command. The specific command should be "=RAND()*(T$1-1)+1", where "T$1" is the total cumulative annual permits corresponding to the row chosen in (4), that is, the cumulative average annual permits corresponding to "Place X in County Y". (In this formula, the value "T$1" has been calculated by a formula based on the minimum number of average annual permits per place that is acceptable. This minimum number is determined by visual inspection of the cumulative permit data.)

   C. Leave the 3rd column blank. This column will be used to copy and sort the random numbers generated in (7b) in value format (as opposed to equation format).[11]

   D. In the fourth column, insert an equation to look up the combination of place and county represented by the random number in column 3. The specific command should be "=VLOOKUP(V4,L4:INDIRECT("N"&V$2),2)", where "V4" is the random number, "L4" is the start of the VLOOKUP table (with L being the column defined in (5) and "INDIRECT("$NS"&V$2)" indicates the end of the VLOOKUP table with N being the column that holds the concatenated place name and county name and "V$2" being the row identified as corresponding to 90% of the state average annual permits. The final"2" indicates that it is the second column in the VLOOKUP table (the concatenated name) that is wanted.

To generate the sample plan in this table, copy the random numbers generated in the second column into the third column and sort in ascending order. This ensures that samples that are to be taken in the same place are contiguous. If multiple sample plan options are desired, copy the four columns of the table and paste as many times as desired to the right of the original four columns.[12]

The result of these 7 steps is a table containing (among other things) 63 concatenated place names and county names that represent the 63 places where samples are to be taken. However, many of these 63 concatenated names will be the same. For example, if 15% of the permits are associated with one place, approximately 15% of the samples should be taken there, for a total of 0.15*63 or approximately 9 or 10 samples.[13]

A final step is to generate a plan that lists each place to be sampled once, along with the number of samples to be taken from that place. To generate this list, start with the four column table generated above.

1. Using the "DATA, Advanced" command, generate a list of the unique place names listed in fourth column of the table. To do this, specify the range of names (such as W3:W66),[14] select "Copy to another location" and "unique records only" in the options, and then specify W68:W132 as the destination.[15] A unique list will appear in rows 68 to whatever the maximum number needed is.

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[11] The reason for this column is that the Excel RND command updates each time the spreadsheet is updated and it is easier to manage the random numbers if they are captured and pasted as text rather than constantly changing.
[12] Currently, the files PNNL uses are set up to provide 14 sample plan options.
[13] The calculation shown here would be for a proportional sample. The DOE study uses a proportional random sample and the "random" element means that the samples required from this place could vary from as low as 4 or 5 to as high as 15.
[14] Note that the Data/Advanced command requires the inclusion of a column title. In this case, cell W3 is labeled "location" and cells W4:W66 contain the 63 sample locations.
[15] W68:W132 is chosen here because it leaves 1 row between the four column table and the start of this new table. The first cell W68 will contain the column title found in cell W3. The cells W69:W132 will contain the unique locations. If there are not enough unique locations to extend to row 132 (as typical), the cells that do not contain a unique location will be left blank.

2. Add a new column entitled "Count" next to the list of unique names. Use a command such as Excel's COUNTIF command to count how many times the unique location occurs in the original 4 column table. An example command is "=COUNTIF(W$3:W$66,W69)" where W$3:W$66 defines the list of locations in the original table and W69 is the first unique location.

3. Add a row below the list of unique locations and entitle it total. Sum all the counts for each location in the table to ensure that they sum to 63.

4. Format the table as necessary as this final table will be the sample plan that is copied into a Word document and transmitted to the project team for approval.

Again, if multiple sample plan options are being generated, repeat these 4 steps as needed.

B.4. Sample Plan Substitutions

See Section 3.3 for a detailed discussion of sample plan substitutions.

Appendix C – Questions to be Addressed at Stakeholder Meetings

The following questions are to be addressed at the stakeholder meetings.

C.1. Sampling Plan Discussion

1. What is the relationship between the “places” identified by the Census Bureau and the jurisdictions that must be contacted for sampling purposes?

2. Can all the “places” be sampled?

3. Is there any part of the state that is not adequately covered by the Census Bureau data?

   For example, in the Kentucky study, it was discovered that approximately half the homes were constructed outside of any code-enforcing jurisdiction, and therefore Kentucky homes were not well represented by the Census Bureau building permit data. However, data was available for plumbing permits and that data was used to generate a sample plan.

   If so, how could that part of the state be sampled? (In an earlier Montana study, data on new electrical hookups was obtained from state permits and used to develop the sample.)

4. Is there additional data besides the Census Bureau data that should be included in the sampling plan to increase its validity and credibility?

5. Is there any reason to apportion part of the state sample to any particular climate zone in the state? (For example, if one climate zone has significantly different envelope requirements.)

6. Is there any reason to use something other than three years of Census Bureau data in the initial sampling plan?

   For example, if expected future construction is better reflected by the most current year rather than the average of the last three years, perhaps the most current year should be used.

7. Are there multiple energy codes in use within the state?

   Home rule states may have multiple codes adopted. States may also have stretch codes adopted in some parts of the state.

   If so, how should the sampling plan be modified to reflect this?

   One approach is to consider each section of the state with a specific code as a “mini-state” and to sample each “mini-state” as if it were a state. This will increase the total sample size required within the state.

8. Are there any proposed sampling locations that are so remote that they should be replaced by similar locations that are less cost prohibitive?

   In a strict proportional random sample, a very small jurisdiction that is isolated geographically may be chosen for the sample. With care, this location could be replaced with a location with similar characteristics that is not as remote in order to reduce travel time for the project team. This substitution must be done thoughtfully to minimize introduction of bias into the sample.

9. Are there any proposed sampling locations that have other problems associated with them? If so, should these locations be avoided?

   There could be jurisdictions that are notably uncooperative or other problems which would limit the project teams' ability to gather complete and valid data.

C.2. Analysis Prototype Review

PNNL has developed prototype single-family home models[1] that are used in nationwide and state analyses for DOE. The project team should review these models to ensure the models adequately represent homes that are being built in their state and generate buy in from the stakeholders.

C.3. Data Collection Form and Data Processing

As part of the initial sampling plan, PNNL will develop a state-specific data collection form that will include input fields for all of the information needed to complete the study.

1. Does the data collection form contain all energy code requirements for the state?
2. Does the data collection form contain any information that does not need to be collected?
3. Does the data collection form lack any information that should be collected?
4. Who will be the representative of the project team who will interact with PNNL on matters regarding data quality and data processing?
5. PNNL will work with the project team to develop a customized data collection form and process for providing data to PNNL.
6. PNNL will process the data into its analysis environment once it is provided by the project team.
7. PNNL will subject the data to a series of quality assurance and quality control steps to ensure that the data is reasonable and internally consistent.
8. PNNL will interact with the designated representative(s) of the project team to resolve any QA/QC issues.
9. No data that allows identification of specific homes, builders, jurisdictions, code officials, or owners should be supplied to DOE or PNNL.

C.4. Project Team Roles & Responsibilities

1. What are the roles and responsibilities of the project team and its contractors and how will they be coordinated?
2. Does the project team have the support of all necessary stakeholders?
3. Does the project team have good relations with the jurisdictions to be sampled?
4. How will the project team contact jurisdictions?
5. Does the project team have good relations with the building community, either on its own or through the jurisdictions to be sampled?

[1] Available at https://www.energycodes.gov/development/residential/iecc_models

6. Does the project team have all the capabilities needed to conduct the evaluation (e.g., capacity to perform blower door and duct leakage testing)?

7. How can the project team maximize the number of observations it obtains from the minimum number of home visits?

C.5. Project Schedule

1. What is the project team's overall schedule for the project?

2. When does the project team anticipate:

   A. contacting jurisdictions to sample?

   B. beginning field data collection?

   C. ending field data collection?

   D. beginning data entry?

   E. ending data entry?

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