Methodology for Calculating Potential Energy Savings from Improved Energy Code Compliance

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Abstract

Over the past 5 years, there has been immense progress in states and municipalities adopting energy codes. As of today, 37 states, covering almost 90% of the US population, have adopted at least the 2009 International Energy Conservation Code (IECC). However, adoption is only the first step to more efficient buildings. To generate energy savings, builders need to comply with the code; it is often difficult to ascertain rates of compliance. There have been many studies done to evaluate code compliance over the years, however, different studies use different methodologies; making it difficult to compare within or across states as well as across time. Moreover, compliance studies did not typically collect information in such a way as to calculate the potential energy savings from moving from non-compliance to compliance. In 2014, 8 states began work on a United StatesDepartment of Energy (DOE) funded project that included a code compliance assessment methodology adapted from work done in the Northwest United States designed to ultimate calculate potential energy savings. Instead of trying to assess compliance among the dozens of requirements within any given residence; this methodology focuses on nine items responsible for the preponderance of savings. It was found that non-compliance centered on lighting, excessive duct and air leakage, poor installation of insulation, oversizing of heating and cooling equipment and substandard duct design. The Midwest Energy Efficiency Alliance (MEEA) along with the Kentucky Department of Housing, Buildings and Construction (DHBC) and the Kentucky Department of Energy Development and Independence (DEDI) received funding to do this work in Kentucky. This paper will describe the methodology in detail; discuss how the study methodology was implemented in the field and provide results on the amount and type of energy code non-compliance in Kentucky.

Introduction

Energy codes provide significant potential energy savings. However, much of that potential can remain unrealized if the dwellings built to the energy code do not comply with it. Enforcement is key . However, because enforcement typically occurs at the municipal or county level, there are often inadequate resources to properly enforce the energy code. (either due to lack of personnel time or inability to properly train personnel to do an adequate job).

Since jurisdictions have limited resources, it is vital to target policies and actions designed to increase compliance. Two important questions need to be answered: What is the actual level of code compliance? What are the main sources of non-compliance . Answering these questions will facilitate the development of effective policies aimed at improving compliance.[1] To answer these questions, a methodology is needed that will measure energy code compliance on a sufficiently granular basis to divulge the needed information.

There have been many attempts to measure energy code compliance over the last 25 years with intermittent success due to the inherent difficulties. (Misuriello, 2014) These studies have been plagued with several problems including: overly expensive, susceptibility to bias, not designed to

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[1] These questions can also help states with developing plans to meet the 90% compliance requirement specified in the American Recovery and Reinvestment Act. In addition, while utilities are interested in funding code compliance improvement efforts. They won't do it unless there is a way to measure the effect of their efforts.

generate energy savings estimates from non-compliance and variability in study methodology across different studies

To address these issues, In 2014, the DOE funded seven teams (for eight states; one team covered two states) on a project that aimed to measure the efficacy of code compliance improvement efforts. (DOE, 2014) One of the states to receive funding was the Commonwealth of Kentucky under a proposal submitted jointly by the DHCD, DEDI and MEEA[2][3]. The project is divided into three phases. (DOE 2014) The first phase of the project, a baseline compliance assessment has been completed. Phase 2 of the project consists of a code compliance improvement program. Phase 3 will be a second code compliance assessment done with the same methodology as Phase 1 designed to determine if there has been any improvement due to the program. The protocol is designed to measure residential energy code compliance in such a way as to determine energy savings[4].

This paper will describe the methodology of the protocol (including the ways the effort in Kentucky diverged from it) and to report the baseline energy code compliance across the state (both as a whole number and per measure) along with associated potential energy savings of moving from non-compliance to compliance. Following is an outline of the major topics covered in this paper.

Description of the Energy Code in the Commonwealth of Kentucky

In Kentucky, the DHBC, adopted in 2011, an amended version of the 2009 IECC for residential dwellings[5]. (ICC, 2009) The IECC provides three compliance paths: prescriptive, UA trade-off and performance. The prescriptive path simply requires a builder to install a minimum amount of insulation without allowing for trade-offs. The UA trade-off uses a DOE developed program called ResCheck. ResCheck allows, for a given climate zone, the ability to trade-off among envelope requirements. The performance path allows the use of software to design a suite of requirements that meet the energy code as long as the requirements produce an energy budget (in dollars) that is less than the energy budget for a standard reference design for the same home geometry. The methodology described is geared to the measurement of compliance against the prescriptive requirements.

While the energy code is set by a state agency and is mandatory statewide, enforcement like much of the United States is done at either the city or county level. In Kentucky, enforcement occurs primarily in the most populous municipalities and counties (although the rigor of the enforcement varies depending on resources). However, in rural cities and counties as well as in less populous counties (typically places with small amounts of construction and concomitant small amount of fees), there is often no enforcement. So, while there is a mandatory requirement to meet the energy code, this requirement is often not enforced due to lack resources. This is an ongoing problem across the United States

Description of DOE Methodology

DOE Methodology

In 2011, the Northwest Energy Efficiency Alliance conducted a code compliance survey (NEEA, 201x) based on evaluating individual requirements. This was a change from previous studies that focused on all the code requirements for a given dwelling. This approach was used in

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[2] For reference, the name of this project is the Kentucky Residential Code Compliance Improvement Study (KRCCIS)

[3] The project is divided into three phases: baseline compliance assessment; program implementation and post-program compliance assessment.

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[5] Basement insulation is only required to go down 4 feet and duct sealing tests did not become a requirement for an additional 2 years. The other requirements are consisted with the unamended 2009 IECC.

the original assessments conducted by the DOE in response to the requirements of ARRA in 2009. (PNNL, 2009). While a good start, this original methodology had problems. (DOE 2013)

With those issues in mind, the DOE has amended its methodology to line up with the work done by NEEA. (PNNL, 2004) The methodology is based on a randomized sample of observations. The observations center around eight key requirements chosen because they represent over 90% of the potential energy savings embodied in the energy code. Inspection teams were required to gather 63 sets[6][7] of observations of the key requirements: exterior wall insulation, foundation insulation, ceiling insulation, window U-factor and solar heat gain coefficient, percentage of high efficacy lighting, duct leakage and air leakage.

Beyond these requirements, the assessment team in Kentucky was asked to make additional observations.[8]

1. Collect data to allow for 63 Manual J calculations designed to determine whether installed heating and air conditioning units were appropriately sized.
2. Collect data on the installation of ducts in order to determine whether they were sized correctly as per Air Conditioning Contractors of America (ACCA) Manual D.
3. Collect air flow measurements from registers using a flow hood. The purpose being to determine whether the correct amount of air is reaching its intended target.

A key point of the assessment was the distribution of inspections across the state. Kentucky was divided into its component counties and cities and the amount of construction from each authority having jurisdiction (AHJ) was determined. PNNL then used a random number generator program to determine the number of sets of data that needed to be collected from each jurisdiction so that the total reached 63[9]. For example, if Fayette County (the county that includes the city of Lexington) was slated to collect 5 sets of data. This would mean that the inspection team would need to inspect a sufficient number of homes in the county to observe 5 examples of each of the nine items listed above. On average, the team would need to inspect at least ten homes in the county to collect the 5 sets.

Unlike previous assessment methodologies, DOE allowed only one visit to a given dwelling.[10] As a result, the assessment team needed to make as many relevant observations as possible for any particular dwelling. (DOE also strongly encouraged teams to make as many observations of non-key requirements as possible).[11] Ultimately, 140 homes were visited to gather the 63 sets of observations.[12] The additional cost to visit the large number of sites was mitigated by

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[6] A set consists of one observation of a key requirement. Because of construction volume, many jurisdictions required the observation of several sets.

[7] PNNL determined that 63 observations were sufficient to determine whether the program activities in Phase 2 actually produced changes in the compliance rate of an individual measure.

[8] This approach to data collection with respect to HVAC is aimed at getting at the need for a holistic approach to HVAC design. Assuming units are sized correctly, the duct system (by both sizing and leakage) needs to deliver the conditioned air. To know whether the system will do so, the size of the unit, the design of the ducts (both in terms of cross sectional area and run lengths and material) and the amount of duct leakage need to be known.

[9] 63 was the minimum of observations for each identified requirement. The protocol required observations until every identified requirement reached 63 observations. Since the inspection teams were required to mark down every possible observation at each site, inspectors made more than 63 observations for several of the requirements.

[10] In previous assessments, the relevant unit of measurement was a home and consequently up to four visits were made to a given site. The concern is that builders will alter their practices if they know an assessment team is coming.

[11] DOE provided each team with a sheet that listed all of the code requirements for a given state

[12] This applied to a given jurisdiction. For example, in Fayette County, 10 site visits were needed to collect the five sets of observations.

the fact that inspection teams did not have to wait for a given address to go through the whole construction process, a major time saver.[13]

Description of Strategy for Gaining Access to Sites

Once the randomized sample was developed, attention turned to the difficult problem of getting access to the sites. Previous studies faced the issue of not being able to gain access to the identified construction sites. This failure tended to bias inspections towards builders who were more "confident" of their homes (builders who are not as confident won't allow access on the concern that their construction practices will be found deficient).

As a result, a procedure was designed to maximize the project's ability to gain access to the sites that were randomly chosen. First, an outreach manager was hired. This individual was a retired state code official who was well-known and respected by the construction community across the commonwealth. Second, the project identified how to determine which addresses to inspect. The Commonwealth of Kentucky has instituted a statewide HVAC permitting system for all residential dwellings. Consequently, unlike other states where construction permit data must come from the individual AHJs, all the addresses under construction are located in one place.[14] Once a list of permits for a given county was identified, the outreach manager contacted the builders for a given address. The outreach manager would explain the rationale of the project as well as the mechanics of the inspection in order to allay concerns and receive permission to go on site. Once that permission was granted, the company employing the inspectors contacted the builders to schedule the inspection. For those construction sites that were still active[15] and for which contact was made, there was only a 5% rejection rate.

Assuring the Quality of The Gathered Data

The project built-in multiple levels of quality control for the data. As the data was collected, it was inputted into a PNNL developed tool called the RCD; which is a basically an excel spreadsheet designed to ease the use of the data. Both the inspection teams and MEEA reviewed each of the data collection sheets to look for anomalous data (an example would involve inputting an obviously incorrect R-Value such as R-30 for foundation insulation walls). Second, both MEEA and PNNL went through each of the entries in the excel spreadsheet. All anomalous results were marked and then reviewed with the inspection teams until all issues were resolved.

Analysis of Data

Once the data was scrubbed, it was sent to PNNL for analysis. This analysis focused on identifying those code requirements that were found to be in non-compliance in at least 15% of the samples. To calculate the potential energy savings for each requirement, the analysts would calculate the energy savings that would be generated if all of the non-compliant observations became compliant. In the case of Kentucky, the five major requirements that generated non-compliance included:

1. Exterior wall insulation (typically as a result of poor installation)[16]
2. Air sealing
3. Duct sealing

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[13] The field inspection time amounted to about 1 hour per house. The major cost was in travel.
[14] This is obviously not the case in most states.
[15] In many cases, by the time contact was made, construction had been completed.
[16] Based on the RESNET installation protocol.

4. Lighting efficacy
5. Sizing of HVAC equipment.

It is important to note that in the case of lighting efficacy, energy losses were completely electric while losses for the other three included both natural gas and electricity[17].

Summary of Results

The following summary of results will include both the identified requirements along with the efficiency requirements for HVAC equipment and the internal analysis done to determine whether contractors were appropriately sizing the equipment.[18] The results will be presented as a series of histograms that show the distribution of observations for a given requirement.

Exterior Wall Insulation

For exterior wall insulation, the results indicate that the majority of builders across the state install insulation meeting the minimum R-value requirement. However, the observations indicate that the installation is often done poorly (2/3 of the observations were either Grade 2 or 3) which undercuts the potential energy savings.[19]

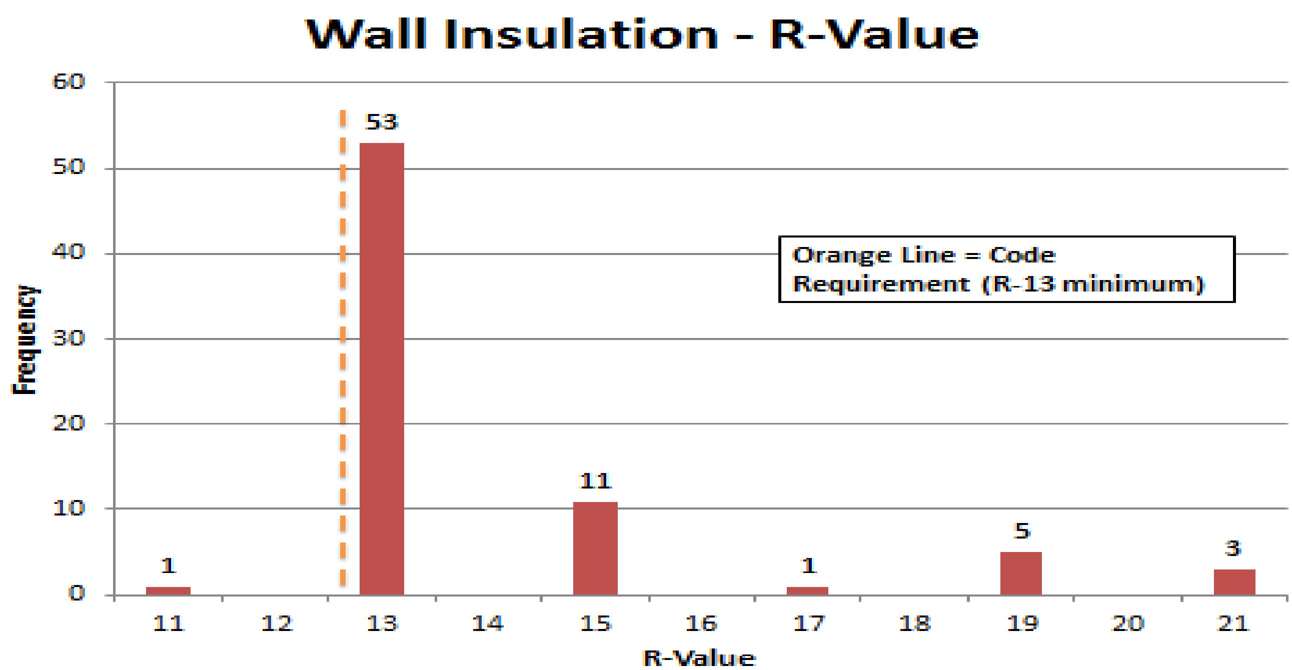


Figure 1. Wall Insulation R- Value

[17] An additional complication involved the type of HVAC equipment. A significant percentage of homes in Kentucky use heat pumps which would result in exclusively electricity savings from improving code compliance as opposed to the mixed fuel results of having air conditioners and forced air furnaces.

[18] Additional data was gathered that will eventually allow the project team to determine whether ducts were designed properly and ultimately whether rooms within a given home were receiving the appropriate conditioned air flow.

[19] To determine the quality of the installations, the on-site inspectors took pictures of several of the installations and these pictures were presented to a group of stakeholder experts. These opinions were then combined with the opinions of the on-site inspectors to arrive at a conclusion. Obviously, judging the quality of installations is not a strictly quantitative exercise.

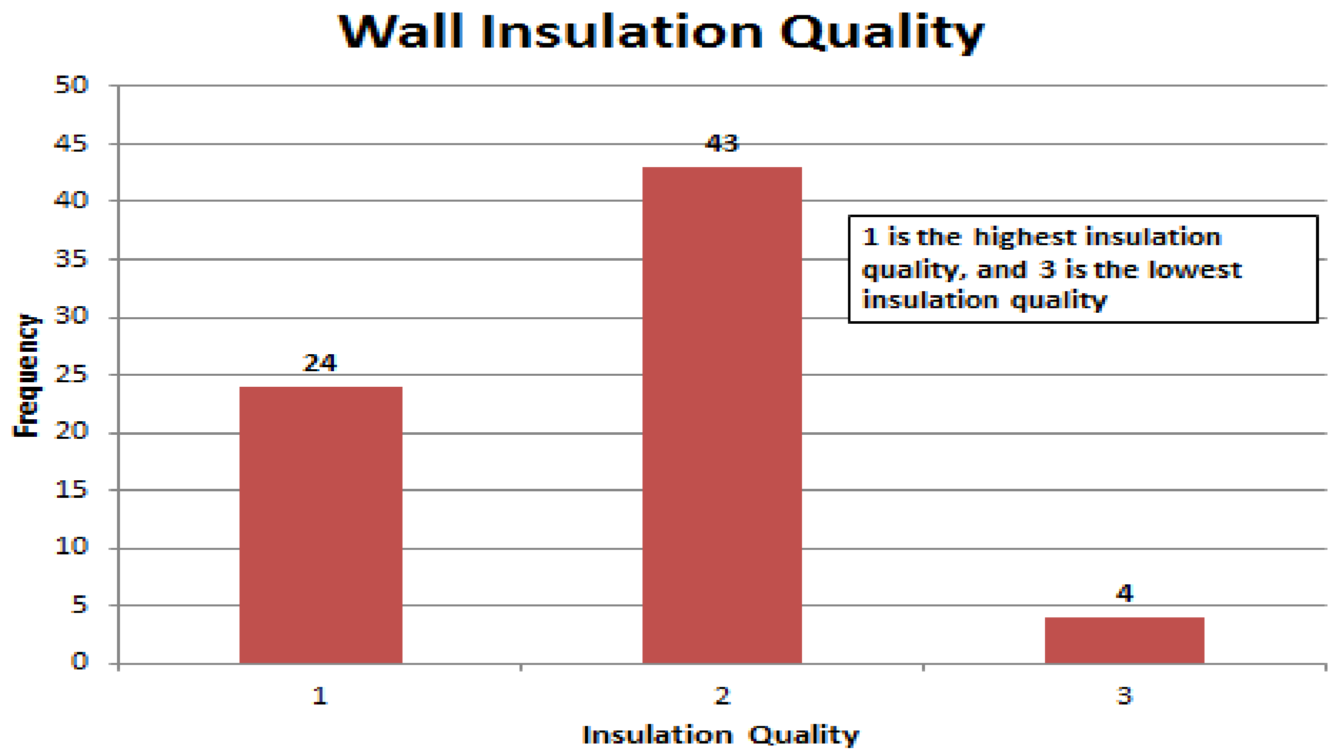


Figure 2. Wall Insulation Quality

Air Sealing

The results of the blower door tests are among the most interesting. The results show a wide range of results ranging from under 1 ACH50 to 20 ACH50 (with 7 ACH50 being the code value). 1 ACH50 indicates an extremely air tight homes (roughly the levels required by a home built to Passive House standards). 20 ACH50 is the type of result found in poorly built existing homes. The results indicate that many builders have learned how to air seal homes well but that testing is still necessary as many builders either do not try or do not know how to air seal homes. Moreover, air sealing is clearly an area where training has significant potential given the energy savings inherent in air sealing.[20]

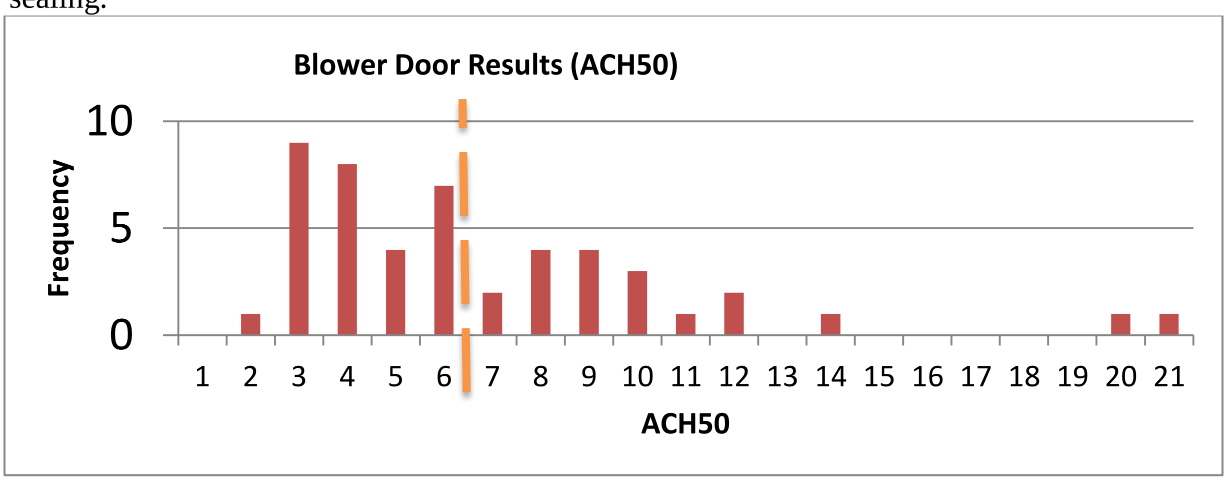


Figure 5. Blower Door Results

[20] Data sheets are currently being analyzed to better understand what deficiencies exist in homes with poor air sealing.

Duct Leakage

Duct sealing results showed an odd dichotomy. The inspection protocol mandated that ducts needed to be tested (if the opportunity exists) regardless of whether the ducts are fully in conditioned space or not.[21][22] For ducts that were not fully in conditioned space (those that would need to be tested under IECC requirements), the duct leakage levels were typically within the energy code mandated levels. For ducts fully in conditioned space, however, duct leakage rates were extremely high; as if builders assumed that there would be no adverse consequences to having extremely leaky ducts. This type of result was found in the other states that did surveys. This leads to two points.

First, the duct testing requirement (show cite) is not the same as the duct sealing requirement (show cite). Ducts are required to be sealed regardless of their location. Second, there is significant debate as to the energy effect of having leaky ducts located fully within conditioned space. It will be relatively simple to communicate the requirement that ducts must be sealed regardless of location; the effect on energy use for sealing leaky ducts fully in conditioned space remains undecided.[23]

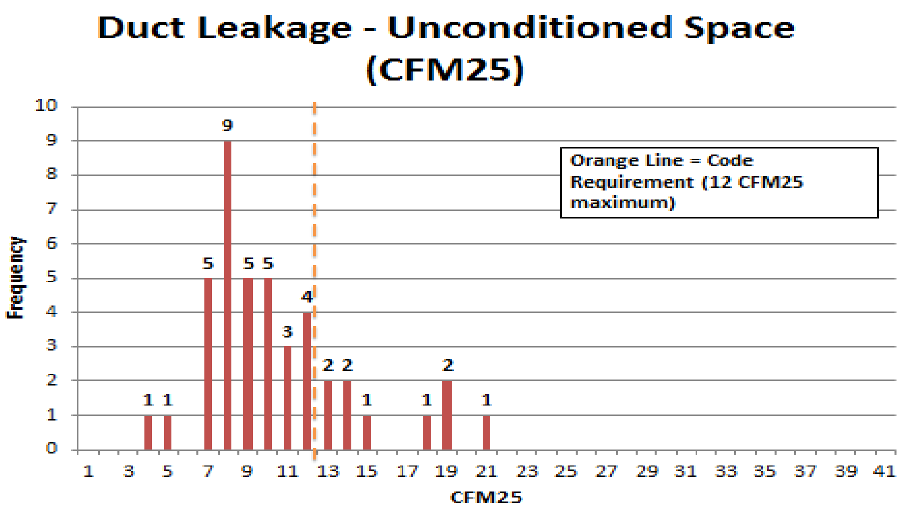


Figure 6. Duct Leakage in Unconditioned Space

[21] The Kentucky State Energy Code did not, until June 2015, require duct testing in any situation. In the model code, duct testing is not required if the ducts are located completely within conditioned space.

[22] By the Kentucky State Code, ducts do not have to be tested if they are 100% inside the conditioned space.

[23] Well sealed ducts (whether in conditioned or unconditioned space) remain important in terms of occupant comfort..

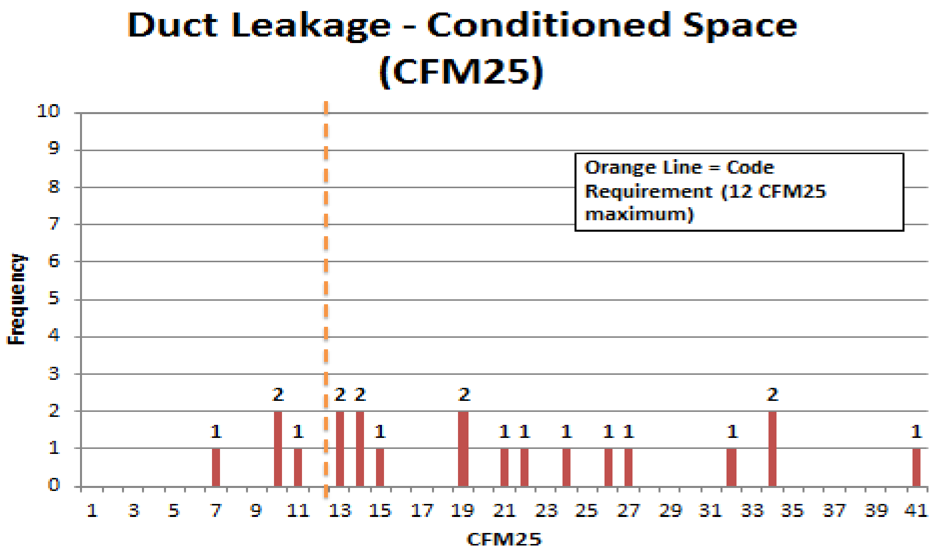


Figure 7. Duct Leakage in Conditioned Space

Lighting Efficacy

The requirement in the 2009 IECC is to have at least 50% of lamps within a home meet the efficacy requirements outlined in (citation). The inspection results revealed a two-headed distribution. Typically, a home either had no (or almost no) high efficacy lamps or it had well over the 50% threshold. Improving compliance with this requirement would have a significant effect on electricity use. Research is being done as to why there is resistance to this cost-effective , easy to implement requirement. Preliminary discussions with builders indicate worries with the light quality of compact fluourescent lamps as well as the tendency to fail within certain fiscutres such as can lights.

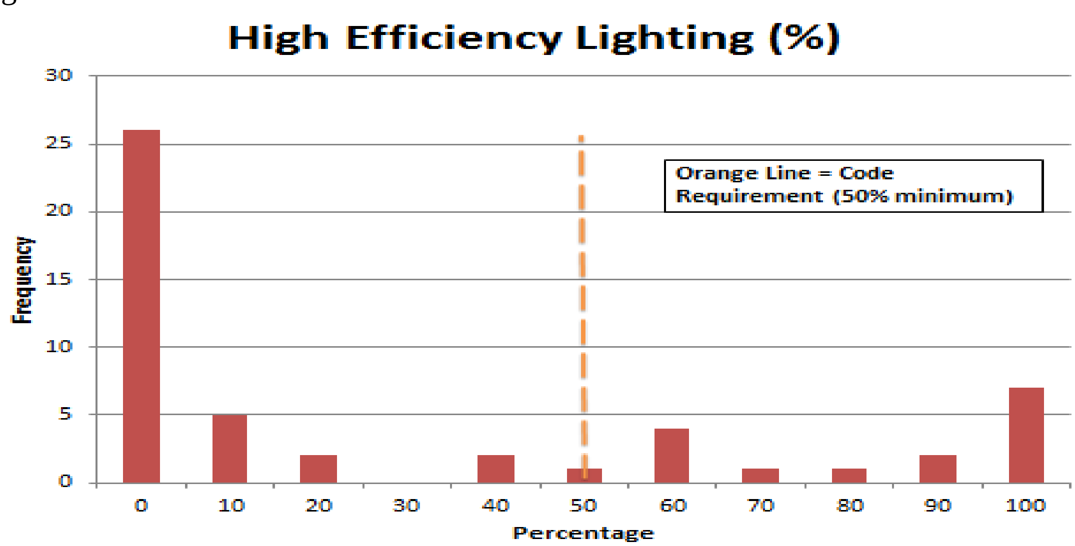


Figure 8. High Efficiency Lighting

Sizing of HVAC

The project team, as was noted above, went beyond the specified requirements in the protocol to require the inspection teams to gather the data necessary to determine whether installed HVAC were appropriately sized as per ACCA Manuals J and S. First, the analysis will attempt to answer the question of whether HVAC units are being correctly sized.[24] This will be done by comparing the size of the installed unit with the size that the Manual J software[25] calculates based on the data gathered on the house. The second question involves the potential energy savings that would come from turning all the oversized units into right-sized units. There is no unique answer to this question as research has indicated a wide range of results dependent on specific conditions. The analysis is being done internally by MEEA with assistance by PNNL.

The results indicate that oversizing is widespread. The median unit is oversized by about 60% or about 1 ton with some units double the amount indicated by a Manual J analysis. There are several possible reasons for this effect:

- Concern about occupant comfort;
- Desires by future homeowner for additions.
- Including the basement as part of the conditioned space even if it is not currently insulated (on the possibility that it will be insulated in the future)

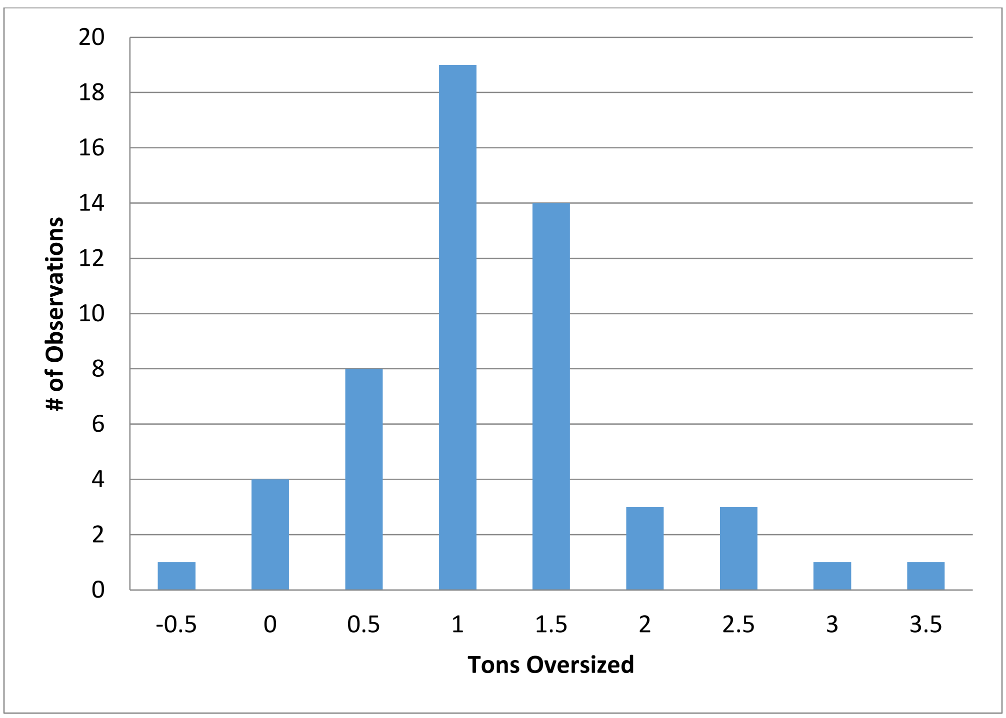


Figure 9. HVAC Oversizing

Ceiling/Roof Insulation

[24] The Manual J program calculates the specific heat load based on heat transfer calculations. However, as units come in specific sizes, the oversizing calculation was made comparing the closest unit in size to the calculated heat load against the unit that was actually installed.

[25] MEEA is using the software program Write Soft ®.

As with exterior wall insulation, observed ceiling insulation R-values generally met code requirements. Installation quality for ceiling insulation was somewhat better than exterior wall insulation quality but still often substandard.

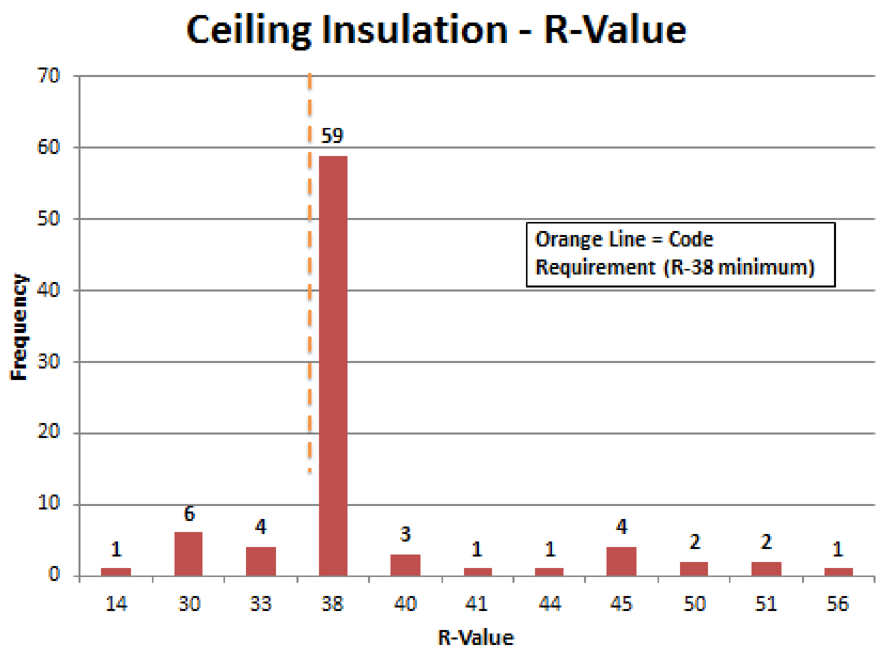


Figure 3. Ceiling Insulation R Value

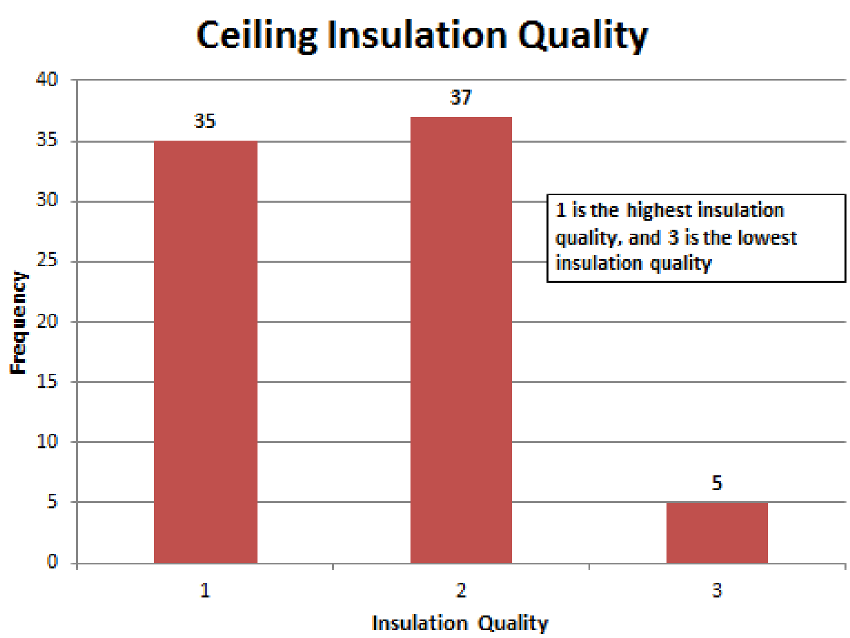
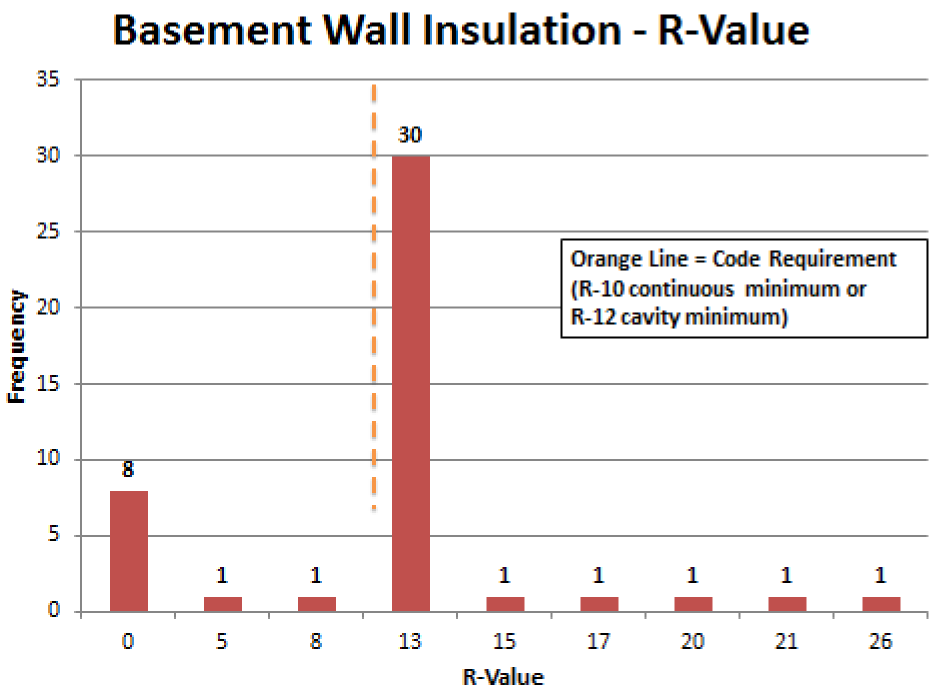


Figure 4. Ceiling Insulation Quality

Much like exterior wall insulation, non-compliance centered on insulation installation quality.

Foundation Insulation

Foundation insulation followed the same pattern as both ceiling and exterior wall insulation. R-values typically met code but inspection teams found numerous instances of poor quality installation.



Window U-Value[26]

Every window observed met code within a narrow range of U-values. This implies that while window manufacturers have stopped supplying non-code compliant windows, there probably isn't much availability of very low u-factor windows.

Heating/Cooling and Heat Pump Unit Efficiency

The majority of forced air furnaces were found to be of the condensing type (<90% AFUE), even though federal requirements (which supersede state code requirements) mandate an efficiency greater than 80 UE. The market in this case has been thoroughly transformed.

The overwhelming majority of cooling units were 13 SEER[27] which indicates that federal requirements are being followed but that there is no significant movement towards more efficient units.

Heat pumps are found throughout the state. Much like furnaces and air conditioners, all observed units were found to be code compliant.[28]

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[26] Charts will not be included for the rest of the requirements as there is little variation in the results.
[27] SEER stands for Seasonal Energy Efficiency Ratio.
[28] Much of this success is probably attributable to the imposition of federal appliance standards.

Potential Energy Savings from Improved Residential Energy Code Compliance

Following is a chart outlining the potential measure level savings from moving non-compliant measures to compliance. (PNNL is currently finalizing the document describing the methodology for calculating these savings.) Preliminary cost estimates have been calculated for implementing the code improvement program outlined in Section 4 at about $150,000 per year. This chart shows that successful efforts to implement programs to improve code compliance are potentially extremely cost-effective.

Table 1. Summary of Potential Energy Savings and Implementation Costs

Measure	**Total Electricity Savings (kwh)**	**Total Natural Gas Savings (therms)**	**Total Energy Savings (MMBtu)**	**Total Electricity Savings (4)**	**Total Natural Gas Savings ($)**	**Total Energy Cost Savings ($)**
Insulation Quality	1,199,555	51,841	9,277	117,436	53,608	171,044
Air Sealing	3,245,622	161,079	27,182	317,746	166,568	484,314
Lighting Efficacy	2,206,514	-17,865	5,742	216.018	-18,473	197,544
Duct Leakage	444,934	13.060	2,824	43,559	13.505	57,064
Total	**7,096,625**	**208,115**	**45,025**	**694,759**	**215,208**	**909,967**
Program Cost						$300,000 [29]

There is an additional point. Right-sizing HVAC also reduces peak demand loads. Analysis by PNNL and MEEA find that simply right-sizing HVAC reduces peak loads by 2.4 MW. Moreover, moving all other measures from non-compliance to compliance saves 4 MW (these are obviously not additive). This provides additional cost savings.

Use of the Data

Phase 2 of the project will take the data and design a training program around the areas of non-compliance. The training for this project will focus on four items: HVAC sizing, air sealing, lighting efficacy and insulation.[30] In addition, there will be an additional training module focused on educating inspectors and plan checkers as to what to look for during inspections to ensure the most thorough inspection possible in the least time.

On top of this training, the project has established a circuit rider program. Over two years, the circuit rider will be meeting with building departments, homebuilders, contractors (HVAC and insulation) and supply houses to discuss obstacles to enforcing and complying with the energy code with particular attention paid to the four items that make up the bulk of non-compliance. Moreover, the circuit rider will also provide information and materials designed to help with addressing the obstacles. Importantly, the circuit rider will, in most cases, make follow up visits to see if the assistance provided is making a difference.

[29] Includes assessment and program. See below for description of program.

[30] The use of conditioned crawl spaces has grown and builders and code officials are anxious to learn how to do this correctly. This is being included even though it did not appear in the data because code officials have raised the concern during circuit rider visits.

Conclusion

Although the Kentucky Code Compliance Improvement Project is still in the middle of Phase 2 of 3 phases, certain facts have been learned about improving code compliance. It has been found that a comprehensive code compliance assessment can be done at a statewide level for a reasonable cost. The compliance assessment can identify areas of improvement from which a code compliance improvement program can be designed. The key fact left to determine is whether the program actually generates improvement. That fact will be known by the middle of 2017. Stay tuned.

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