More Bang for the Buck – Does Increased Code Compliance Result in kWh *and* kW Savings?

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ABSTRACT

The energy benefits of increased code compliance have generally been viewed through the lens of energy savings – kWh and therms. Peak demand reduction as an additional benefit of increased code compliance is a comparatively unexplored area – despite a general acknowledgement that there are electric demand savings (kW) associated with increased energy code compliance. The ability to include peak demand reduction as a component of the code compliance savings has important and significant benefits. The inclusion of demand savings will improve the cost effectiveness of many energy saving programs and it offers a new path for engaging utilities in energy reduction, since the inclusion of code compliance demand reduction may allow utilities to defer, or even eliminate, the construction of new, capital-intensive generating capacity.[1]

The authors investigated this problem using a randomized set of new single-family homes in the state of Kentucky. Information about the building envelope and mechanical systems was collected for 54 homes. Detailed energy modeling was then used to evaluate the potential impact of improved code compliance on peak demand. This paper describes the methodology developed for calculating demand reduction attributable to increased residential energy code compliance and the potential kW savings available. Two independent aspects of demand reduction were analyzed – improved measure level compliance, and HVAC equipment sizing. The potential statewide annual measure level savings ranged from 40 kW to 2,987 kW depending on the measure. The potential statewide annual HVAC equipment sizing savings was 2,373 kW, along with a corresponding annual statewide energy savings of 624,325 kWh

Introduction

States and municipalities began adopting and enforcing energy codes in the mid-1970's, largely in response to the 1973 oil embargo (ASE 2013). Since 1992, more than 4 quads (approximately 1.17 billion MWh) of electricity have been saved as a result of energy codes (Livingston et al. 2014). This impressive level of energy savings continues apace as building codes increase in stringency with each new version, and states and municipalities continue to adopt and enforce updated versions of the energy code.

While capturing the benefits of demand reduction has been a focus in various parts of the country, notably California, the lower peak demand associated with energy code compliance has largely been ignored by researchers, evaluators, code advocates and other stakeholders. This is mainly because the building energy code is designed to specifically address energy consumption but not peak demand. However, many users of the code have broader interests. This paper

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[1] Kentucky does not have Energy Efficiency Portfolio Standard (EEPS) requirements and thus makes an excellent site for this undertaking.

provides a methodology for quantifying the potential energy and peak reduction benefits from improving energy code compliance, including right-sizing of HVAC equipment, in newly constructed single family homes in Kentucky. The paper also quantifies the demand (kW) savings potential on a statewide basis. The consideration of peak demand alongside energy savings will result in a fuller picture of the true benefits of increased energy code compliance. Additionally, and not incidentally, the cost-effectiveness of many programs and interventions are likely to be improved by the inclusion of the demand reduction benefits from increased energy code compliance.

Background

In early 2015, the United States Department of Energy (DOE) released a Funding Opportunity Announcement (FOA) aimed at evaluating energy efficiency in new single-family residential buildings in a three-phase study (DOE 2015). The first phase documents existing construction practices relative to the energy code and identifies opportunities for energy savings in new single-family residential buildings. The second phase conducts targeted training and outreach activities for builders and code officials. Finally, the third phase evaluates energy savings from training activities through a second data collection and analysis effort. Following a merit review, eight teams were awarded funding to proceed with the data collection effort in eight different states. The Midwest Energy Efficiency Alliance (MEEA) was awarded funding to conduct the study in the state of Kentucky. The energy modeling and analysis support for the study was provided by the Pacific Northwest National Laboratory (PNNL).

Data Collection

The study begins with the collection of field data relating to various requirements of the model residential building energy code. The model residential building energy code for the state of Kentucky is the 2009 edition International Energy Conservation Code (IECC) (ICC 2008). There are only two minor changes to the model code as adopted by Kentucky and they do not materially affect the energy use analysis used for this research. For the purposes of this paper, the reference code shall be referred to as the 2009 IECC. While the 2009 IECC includes three different compliance paths, this study focuses on the prescriptive and mandatory provisions of the code to simplify the analysis procedure. While the overwhelming majority of homes in Kentucky use the prescriptive path, one limitation of this methodology is that homes complying via the performance path are not captured.

To support DOE’s effort of developing the FOA, PNNL conducted a sensitivity analysis to identify the code requirements with the highest energy impact and the number of observations required for the energy differences between phase I and phase III of the field study to be statistically significant. These high-impact code requirements are referred to as “key items.” This assessment was conducted using energy simulation with *EnergyPlus*$^{\text{TM}}$ (DOE 2013) by assuming an expected probability distribution of different efficiency levels for each prescriptive and mandatory requirement of the 2009 IECC. As a result of this sensitivity study, it was determined that envelope air tightness was the key item with the largest energy impact and that a sample size of 63 would yield statistically significant energy differences between phase I and phase III of the field study. Accordingly, the data collection teams were instructed to collect at least 63 observations of each key item. Data collection forms and sampling plans for Kentucky were created based on a proportional random sample representative of new single-family residential construction in the state. All permitted, single-family homes were included in the selection pool. This allowed for areas that issued a higher number of permits to be sampled more heavily than areas that issued fewer permits. Figure 1 shows the statewide sampling plan used for DOE's field study in Kentucky.

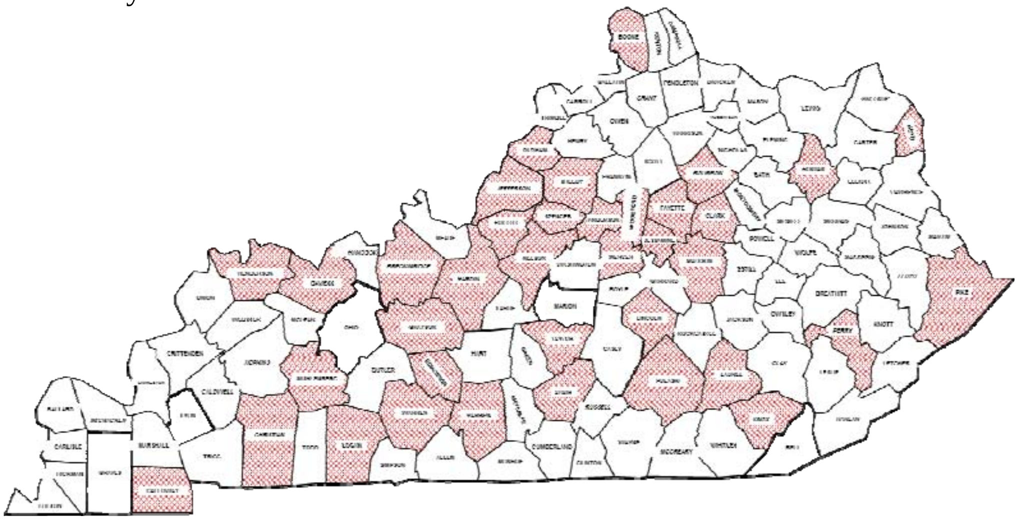

Figure 1. Sampling plan for the Kentucky DOE field study

A key guiding principle of the DOE residential field study was the elimination of the bias that would be introduced if builders were aware that the house was being evaluated. To avoid this bias, the entire data collection effort was designed based on a single site visit to each house. This meant that the data collection team had to visit many more than 63 homes to collect enough observations for each key item, as some key items can only be observed during certain stages of building construction. In Kentucky, a total of 140 site visits were required to collect 63 complete data sets. Another implication of this constraint is that a complete data set of all key items is not available for any given home. The procedure used for performing the analysis while utilizing data sets that are incomplete at the individual home level is discussed in the Consideration of HVAC Equipment Oversizing section of this paper.

Kentucky data

The key items selected for the state of Kentucky are listed in Table 1 along with the actual number of observations collected by the data collection team. Figures 2 through 7 show the distribution of observations for each key item and how they compare to the 2009 IECC prescriptive or mandatory code requirement (there is a single IECC climate zone in Kentucky - 4A). In each figure, the code requirement is indicated by the vertical dashed line and the code value is indicated in white font inside the black box. Values to the right of the vertical line indicate observations that are better than the code requirement while those to the left indicate those that are weaker than code. The bars that are immediately adjacent (to the right) of the dashed line match the code requirement exactly. The total number of observations (n) for each item is indicated at the top of the panel.

Table 1. Key items and number of observations for the state of Kentucky

No.	Key Item	Number of Observations
1.	Envelope Air Tightness (ACH50)	66
2.	Ceiling Insulation (R-value)	86
3.	Duct Air Sealing (CFM25/100 ft^2 Conditioned Floor Area)	64
4.	Above-grade Frame Wall Insulation (R-value)	74
5.	High-efficacy Lighting (percentage)	68
6.	Window U-factor (Btu/hr-ft^2-F)	91
7.	Window SHGC	91

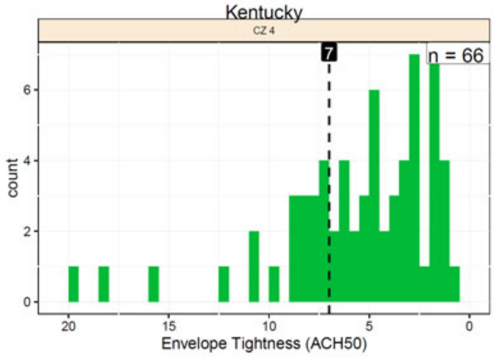

Figure 2. Distribution of envelope tightness

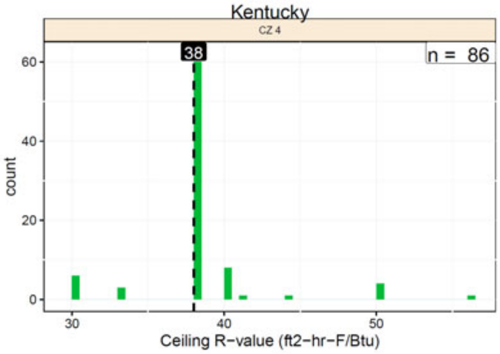

Figure 3. Distribution of ceiling insulation

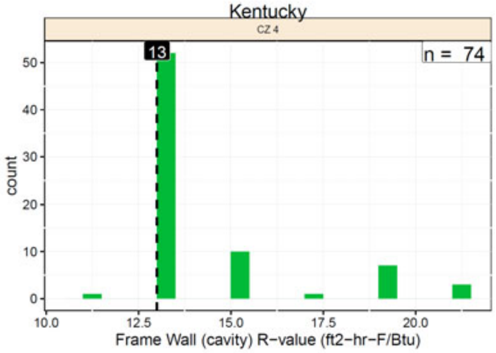

Figure 4. Distribution of above-grade wall insulation

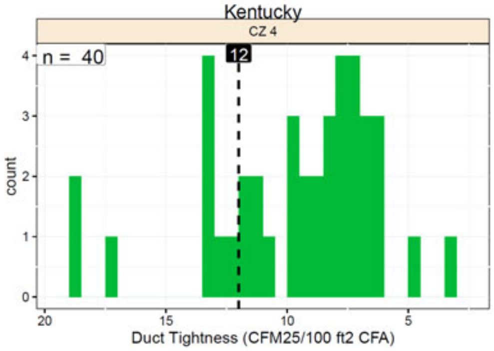

Figure 5. Distribution of duct tightness

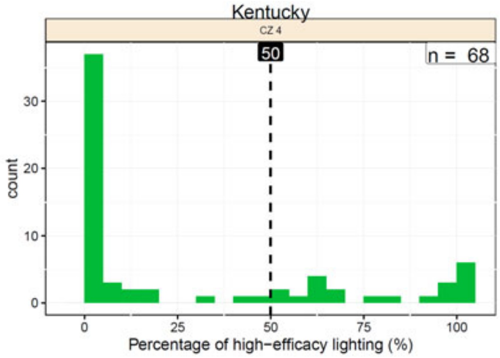

Figure 6. Distribution of high-efficacy lighting

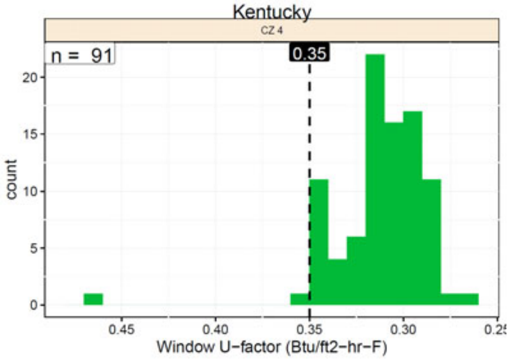

Figure 7. Distribution of window U-factors

Additional data collection

In addition to the data collected for the key items described above, the project team in Kentucky also collected sufficient information to perform Manual J block load calculations for 54 homes across the state (the 2009 IECC requires HVAC equipment to be sized in accordance with the Air Conditioning Contractors of America Manual J [ACCA 2011a]). It should be noted that the study sample size was determined for key item analysis and not for the additional Manual J analysis. Therefore, although the data was collected from the same homes used in the key item analysis, there were not a prescribed number of data sets that had to be collected from a given set of counties. Determining the number of Manual J data sets required for statistical significance, and collecting that additional data was beyond the scope of this study. While the Manual J data set does not carry the same statistical significance as the key item data set, the authors believe it is a robust sample that can be confidently used to assess the state of residential HVAC sizing in Kentucky. Figure 8 is a map showing the distribution of homes (by county) used in the Manual J data set.

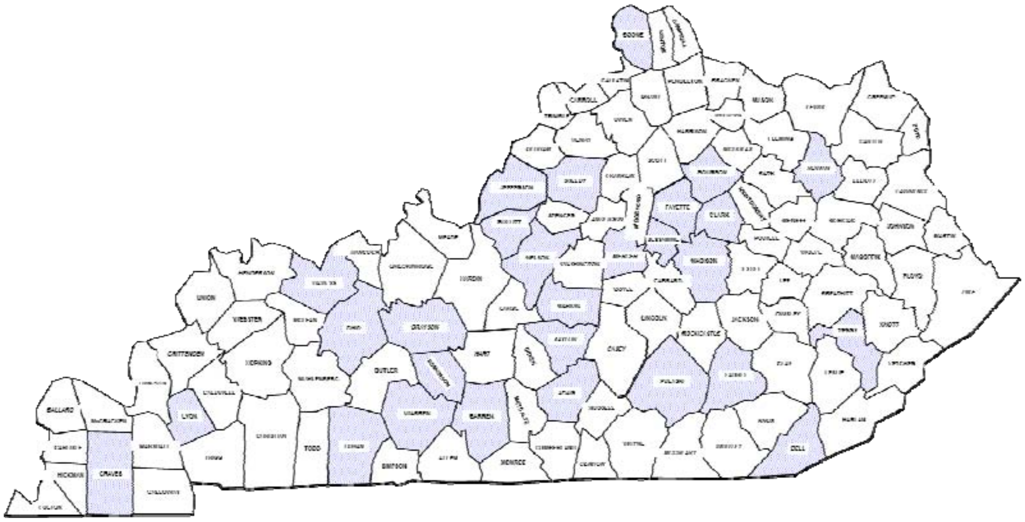

Figure 8. Sampling plan for MEEA’s Kentucky Manual J study.

In order to perform the Manual J block load calculations, the envelope, envelope tightness, and duct tightness data collected in the key item data set had to be augmented. The additional data necessary included the capacity of the installed equipment (Btu/hr or tons of cooling); the type of equipment installed (central air-conditioning system, air-source heat pump, ground-source heat pump, etc.); equipment model number; building orientation; conditioned volume; conditioned floor, wall, and ceiling areas; and window area for each façade. This additional data was collected at the same time as the key item data for a given house. Consequently, the additional Manual J block load data was collected at the “final” stage of construction, when the HVAC system had been fully installed.

Methodology for Estimating Savings

The objective of the DOE field study is to identify building components that are consistently weaker in terms of energy efficiency than what the code requires, and use this information to design training and outreach activities to improve the relevant building practices. The potential energy savings that can result from improving these building components to minimally meet the code requirements are an important consideration in creating training materials that target the most influential items first. The collected field data was first evaluated to select the key items for which more than 15% of the observations were worse than the levels required by the reference code. For Kentucky, this results in the selection of high-efficacy lighting (69% observations worse than code), above-grade exterior wall insulation – which includes consideration of insulation level as well as quality of installation (58% observations worse than code), envelope air tightness (30% observations worse than code), and duct air tightness (17% observations worse than code).

Each of these key items is evaluated in isolation to determine the maximum potential energy savings that can be obtained by improving the observed value to the minimum code requirement. For the purposes of this analysis, savings overlap and interaction between measures was not considered. A separate exploratory analysis conducted by one of the authors indicated little overlap or interactive effects between measures in terms of energy (kWh) savings – indicating that these could be additive. However, this cannot be said about peak (kW) savings as the time of peak is likely different for some of the measures. Additionally, the specific mix of building types in the geographical region of interest to a utility will drive the overall peak reduction for the population. For these reasons, a detailed evaluation of the interaction in peak reduction is beyond the scope of this paper. The evaluation is conducted through energy modeling using *EnergyPlus*, one of the most advanced whole-building simulation engines available today. The potential savings evaluation has three main steps – data review, energy model preparation, and aggregation of results.

Data Review

Data collected by the project team goes through a rigorous QA process to resolve inconsistencies and erroneous data entries. The clean field data is then used as the starting point for analysis. For each of the four key items demonstrating significant non-compliance (high-efficacy lighting, above-grade wall insulation, envelope air tightness, and duct air tightness), the data is reviewed to select only those observations that do not comply with the relevant building energy code requirements.

Energy Model Preparation

Each worse-than-code observation for a given key item selected during data review is used to create a building energy model using DOE’s single-family residential building prototype. All other building components, except the measure being evaluated, are maintained at the corresponding 2009 IECC prescriptive code levels regardless of the actual levels observed in the field. The data collected for Kentucky indicates the common use of four different foundation types – vented crawlspace, conditioned crawlspace, slab-on-grade, and heated basement – and three different HVAC system types – electric heat pump, electric air-conditioner with a natural gas furnace and electric air-conditioner with an electric furnace. Tables 2 and 3 summarize the shares of the different foundation types and HVAC systems observed in Kentucky.

Table 2. Foundation Types Observed and Weighting Factors

Foundation Type	Weight
Heated Basement	53.49%
Slab-on-grade	18.60%
Vented Crawlspace	23.25%
Conditioned Crawlspace	4.65%

Table 3. HVAC Systems Observed and Weighting Factors

HVAC System Type	Weight
Electric AC with Electric Furnace	8.78%
Electric AC with Natural Gas Furnace	47.37%
Electric Heat Pump	43.86%

A set of *EnergyPlus* building energy models is created to represent all variations of heating systems and foundation types observed in the field. The models are simulated using the weather data for Lexington, which is selected as the representative climate location for climate zone 4A in Kentucky.

Aggregation of Results

Annual electric and gas energy use intensities (EUI) are extracted for each building model and weighted across heating systems and foundation types to generate weighted average EUIs. These EUIs are compared with similarly weighted EUIs for building energy models built to minimally comply with the prescriptive and mandatory requirements of the 2009 IECC for all building components in the state of Kentucky. The EUI differences are the potential energy savings that can be achieved by improving the observed worse-than-code values for the key item under consideration to the minimum code-compliant level. This approach evaluates energy lost from non-compliance for each key item taken in isolation.

Demand Reduction

The methodology used to determine potential energy savings can also be applied to estimate the impact of improved code compliance on the peak electric demand of new single-family residential buildings. This is done by extracting the annual peak electric draw from each of the building models and comparing them with the peak demand for the energy models built to minimally comply with the prescriptive and mandatory requirements of the 2009 IECC. The differences in the peak electric draw are weighted over different foundation types and HVAC systems to calculate the average peak demand reduction for a house in the state of Kentucky. However, the statistical significance of the demand reduction calculated in this manner cannot be validated because the sample size was not designed with the consideration of kW reduction.

The energy simulation is conducted using Typical Meteorological Year (TMY3) weather data. The TMY3 weather data are produced using weather data from 1991-2005 and designed to represent typical rather than extreme conditions (Wilcox and Marion 2008). Thus, they are likely to underestimate peak loads for residential buildings which are dominated by building shell losses. Unlike, the potential energy savings, the potential electric demand reductions calculated for different measures are not additive because the time of peak is different for some measures. While determining the co-incident peak for the measures analyzed was beyond the scope of this study, the analysis approach does allow the relative impact of each measure on the peak electric draw to be calculated.

Consideration of HVAC Equipment Oversizing

Since the DOE data collection protocol prohibited data collectors from visiting a home more than once, not all required Manual J data was collected for each individual home used in this study. For example, when the installed HVAC equipment could be observed, the R-value of wall insulation could often not be verified, since gypsum board had already been installed. In these instances, the average value from the key item data set is used (homes typically did not have plans or other documentation available for review). The range of values for envelope components missing from the Manual J homes typically had a clustered value (a significant majority of the homes having the same, or a similar value). For example the range of R-values observed in wall insulation was R-11 to R-21, but 72% of the wall insulation installations observed had the code required value of R-13. Similarly, both the average and median window U-factors were 0.31. The range of values for duct and envelope tightness was significantly larger. However, there were far fewer instances of these values being missing from the Manual J data set. The load calculations are performed using *Wrightsoft* Right Suite, Version 8 (Wrightsoft 2015).[2] The list of values used, the range of values, the average value, and number of occasions they were used is shown in Table 4.

Table 4. Default values used in *Wrightsoft* sizing calculations

Component	Number of Occasions Used	Default Value Used	Minimum Value	Maximum Value	Average Value	Median Value
Wall Insulation	39	R-13	R-11	R-21	R-14	R-13
Ceiling Insulation	4	R-38	R-14	R-56	R-38	R-38
Window U-factor	32	0.31	0.27	0.47	0.31	0.31
Duct Tightness (CFM25/100 ft^2 CFA)	8	12.75	3.1	40.4	13.2	10.2
Air Sealing (ACH50)	8	5.6	0.51	20	5.6	4.85

Similarly, building orientation data was not collected for each of the buildings in the data set. *Wrightsoft* automatically calculates the orientation with the maximum load. In the instances where a building orientation was not provided, the orientation with the maximum load is used as the design load.

In order to determine the incidence and extent of oversizing of air-conditioners in current construction practices, the calculated load is compared to the capacity of the installed equipment

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[2] *Wrightsoft* is an ACCA approved software program that is commonly used in Kentucky and is acceptable to the state code enforcement agency – the Department of Housing, Buildings and Construction (DHBC).

for each of the 54 buildings in the additional data set. Each home in the data set is created in *Wrightsoft* as a separate file. When available, the specific characteristics for that building, including floor areas, ceiling area, roof construction type, wall construction type, wall and ceiling insulation values, window and door U-factors, window SHGC, envelope leakage, duct tightness, building orientation, and weather location data is input into *Wrightsoft*. As noted above, when particular building characteristic was not available for a specific home, the average value from the full data set is used.

The unique load required for each building is then calculated by *Wrightsoft*, including the latent load, based on the specific envelope and system values for each building. The total building load is then compared against the installed equipment to determine if the installed system is oversized for the building as-built. In other words, the load for the building is determined using the actual measures or components installed. The idea is to determine if builders are "right-sizing" the systems for the buildings they actually build. It is not assumed that builders are constructing buildings to code minimum standards. For example, if a given building has above code windows or below code ceiling insulation, those specific characteristics are used in the *Wrightsoft* calculation.

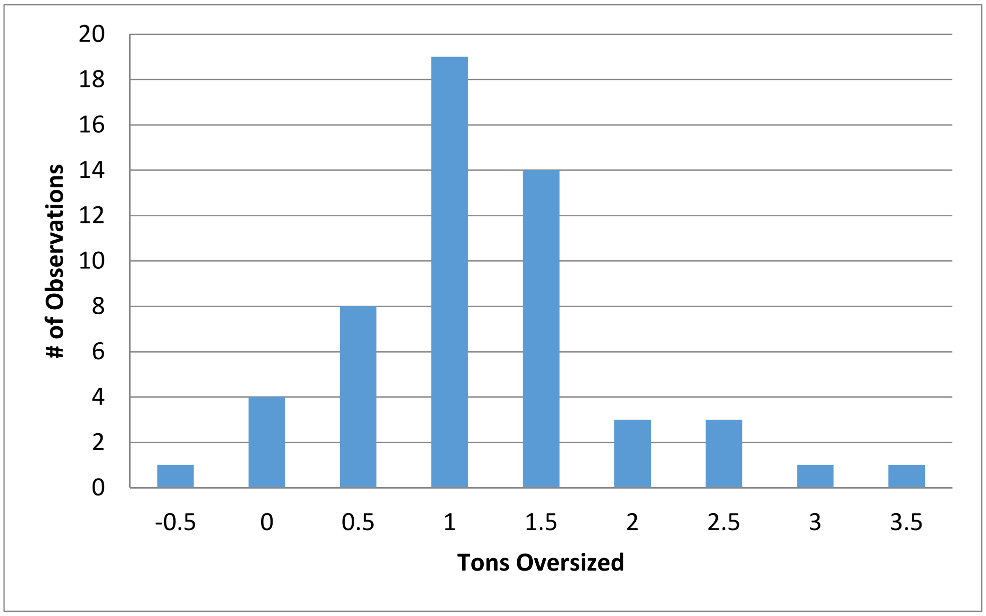

Figure 9. Distribution of oversizing.

In establishing the baseline for the appropriate size of installed units, the calculated design load is upsized to the next standard unit size. This unit upsizing is based on readily available industry standard unit sizes but is not manufacturer specific. For example, if the *Wrightsoft* design load is 25,000 Btu/hr (2.1 tons), the baseline for comparison to the installed unit is upsized to the next size larger unit, or 30,000 Btu/hr (2.5 tons). This sizing methodology is a conservative assumption because ACCA Manual S (HVAC sizing) allows a plus/minus 2,000 Btu/hr consideration when sizing units (ACCA 2011b). Therefore, in the above example, a 24,000 Btu/hr unit would be Manual S compliant (as it is within 2,000 Btu/h of the design load) but a 30,000 Btu/hr unit is conservatively used for the baseline.

Using this methodology, 49 systems were determined to be oversized, four systems were determined to be right-sized, and one system was undersized by ½ ton. The range of installed unit oversizing was from -0.5 tons (undersized) to 3.7 tons (oversized). The average system was oversized by 1.2 tons, with a median oversizing of 1.0 tons. This corresponds to an oversizing factor of approximately 159%. The distribution of the extent of oversizing is shown in Figure 9 above.

Potential Energy Savings and Demand Reduction for Kentucky

Because the field study is focused on new single-family residential buildings built in Kentucky, this dataset represents only a subset of the entire building construction stock.

Key Item Savings

The latest full year permit data provided by DHBC indicates 7,345 new homes were built in Kentucky. This projected construction volume is used to calculate energy savings and demand reduction potential at the state level. Energy costs are calculated based on latest electricity and natural gas costs for the state of Kentucky from the Energy Information Administration (EIA 2016a and EIA 2016b).

Table 5. Potential energy savings from improved code compliance for the State of Kentucky

Measure	Electricity (kWh/year)	Natural Gas (therms/year)	Energy Cost ($/year)
High-efficacy Lighting	2,206,514	-17,865	197,544
Above-grade Wall Insulation	1,199,555	51,841	171,044
Envelope Air Tightness	3,245,622	161,079	484,314
Duct Air Tightness	444,934	13,060	57,064
Total	7,096,625	208,115	909,967

Table 6. Potential electric demand reduction from improved code compliance for the State of Kentucky

Measure	Electric Demand Reduction (kW/year)
High-efficacy Lighting	558
Above-grade Wall Insulation	971
Envelope Air Tightness	2,987
Duct Air Tightness	40

Table 5 summarizes the potential energy savings for the entire state of Kentucky that can be obtained by improving the identified worse-than-code key item observations to meet the minimum prescriptive and mandatory requirements of the 2009 IECC. Table 6 summarizes the associated electric demand reduction potential for each of these key items for the entire state.

Impact of Equipment Oversizing

The impact of equipment oversizing is considered separately in this analysis for simplification. The sizing factors calculated using *Wrightsoft* are used to create a set of DOE’s prototypical single-family residential building models with the associated HVAC system types. The peak electric draw from each model is compared with the peak electric draw for the 2009 IECC code-compliant model to calculate the potential demand reduction for each building model. These differences are aggregated over the foundation and HVAC system shares to arrive at the weighted average demand reduction for the entire state. Analyzing the potential savings if all non-compliant measures were moved to compliance (with the remaining measures being as-built) and all HVAC systems right-sized for these improvements is beyond the scope of this paper.

The estimated collective demand reduction potential from right sizing equipment for all homes is 2,373 kW per year for the entire state of Kentucky. Oversizing HVAC equipment also impacts energy consumption. However, this impact is smaller in residential buildings because typical residential HVAC units and fans cycle on and off to meet the building's heating or cooling load. Interestingly, in the case of heat pumps, oversizing may lead to better energy performance in climates with mild winters by offsetting a portion of the less efficient supplemental electric resistance heat. The simplified approach used in this analysis indicates potential average electricity savings of 85 kWh per home per year in Kentucky from right-sizing HVAC equipment, or 624,325 kWh on an annual statewide basis. Accurate assessment of this impact would require a substantial effort in creating equipment performance curves representative of each unit observed in the field and is beyond the scope of this study.

Conclusions

This study shows that there are kW savings from both right-sizing of HVAC equipment and from improving identified non-compliant envelope measures to compliance. Further study is required in order to understand how these different aspects of compliance interact and combine to produce total kW savings. Therefore, the two results of the study should be viewed as independent findings, and not combined into a single peak demand savings number.

The current estimate is conservative in some ways because it does not include other building types, nor does it provide consideration for co-incident peak demand. The use of TMY3 weather data also likely underestimates the peak demand reduction potential. Additional data is required to adequately address these factors including building component information for new commercial buildings and existing buildings along with the load profiles for each building type. However, the demand reduction estimated by this study is still significant because it qualifies as an additional benefit of improving code compliance that may benefit a utility, beyond energy savings that directly benefit the home-owner.

Acknowledgments

This work was supported by funding from the United States Department of Energy. The authors would like to thank Rosemarie Bartlett, Bing Liu, Mark Halverson from PNNL, and Isaac Elnecave from MEEA for their thoughtful guidance throughout the study. Also thanked are Mark Nussbaum and Rob Olden for their insights on load calculations. In addition, the authors would also like to thank the Kentucky Department of Housing, Building and Construction (DHBC), the Kentucky Department for Energy Development and Independence (DEDI), and George Mann for their invaluable assistance in the data collection effort. Finally, the authors would like to express their gratitude for YuLong Xie and Dan Fortin from PNNL, and Kelsey Horton from MEEA, who put in a significant effort in QA-ing the data and creating data visualizations.

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