Codes to Cleaner Buildings: Effectiveness of U.S. Building Energy Codes

Jeff Deason and Andrew Hobbs, Climate Policy Initiative, San Francisco, CA

Abstract

Building energy codes are used worldwide to promote energy efficiency in buildings. In this paper, we assess the impact of U.S. state energy codes using residential energy use data at the state level. By conducting a regression analysis comparing U.S. states with building energy codes to those without, we measure the realized energy savings of energy codes and compare them to the modeled estimates.

We find a decrease of roughly 10% in household energy use relative to households that were not built under these codes. Given the number of units affected by building energy codes, we estimate building energy codes reduced residential primary energy consumption by 1.3% in 2008. We also observe a shift toward natural gas and away from lesser-used "other" fuels, most notably fuel oil. This finding may reflect provisions in the studied codes that encourage high-efficiency gas units and electric heat pumps. Our results suggest that the combined effect of energy savings and fuel-switching has delivered about a 16% reduction in greenhouse gas emissions from an average code household. In aggregate, this means that building codes reduced 2008 residential building emissions by approximately 1.8%.

Our findings suggest that standard engineering estimates of energy savings are reasonable, at least for the studied codes; if anything, it appears that these estimates may be lower than actual savings. We confirm that building energy codes have reduced greenhouse gas emissions. Our findings also highlight the impact of codes on fuel choice, an effect we have not seen discussed elsewhere.

1 Introduction

In this study, we estimate the impact of building codes in the United States on energy consumption in the residential sector using state energy consumption data. Residential buildings consume 22% of U.S. primary energy and produce 21% of U.S. carbon dioxide emissions, so the potential impact of codes governing this energy use is substantial. Much of this energy (about 54% in final terms or 42% in primary terms as of 2008) is used for space heating and space cooling, though the shares vary by region.

Building energy use for space heating and cooling depends significantly on heat flow into and out of the building, which is controlled by the building envelope. Building energy codes are designed principally to regulate the performance of the envelope. Many building energy codes also affect the choice of heating, air conditioning, and water heating units due to provisions that allow envelope requirements to be traded off against high efficiency equipment (see section 2.3 for more detail). As shown in Figure 1, heating and cooling loads account for more than half of primary household energy use in colder regions and only slightly less in warmer regions. Water heating accounts for approximately 15% of additional primary energy use.

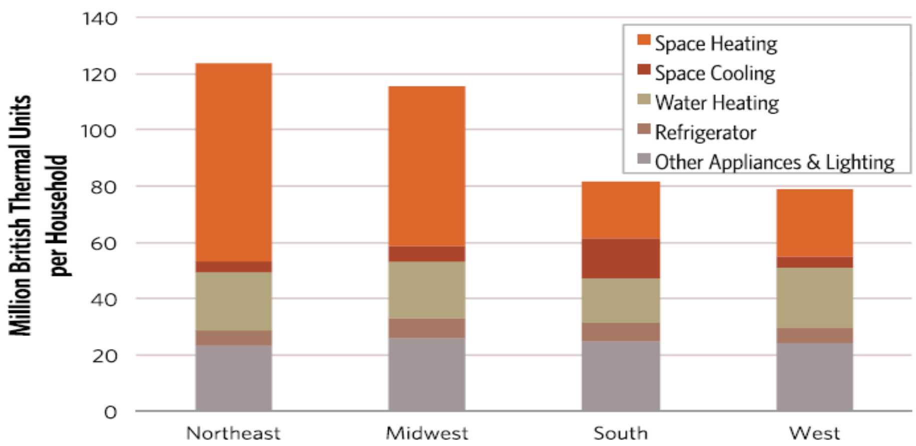

Figure 1. Residential primary energy use profiles vary throughout the U.S.

Building energy codes are widely used and considered an important driver for improving energy efficiency (Metz et al. (2007). For government, codes are inexpensive to implement relative to incentives or financing measures.[1] For homeowners, they encourage efficiency measures at the time of construction, which is generally much cheaper than implementing these measures after building construction.

Section 2 of this paper describes building energy codes in the United States, including their history, development process, and an overview of their provisions. Section 3 reviews the literature on estimates of code impacts. Section 4 describes our methods and the data we used to estimate building energy code impacts. Section 5 presents our results to date. Section 6 discusses the policy implications of our results.

2 Residential Building Energy Codes in the United States

2.1 Current Code Design and Adoption Process

Federal, state, and local government agencies all participate in building energy code design and implementation in the U.S. (see Figure 2). Residential model codes are designed by the International Code Council (ICC).[2] The ICC is a nonprofit open-membership organization composed of representatives from various levels of government as well as building industry professionals and other relevant organizations and individuals. Only governmental members have voting rights, but all members participate in discussions about code design and revision. Codes are currently revised on a three-year cycle. The ICC energy code[3] is known as the International Energy Conservation Code (IECC).

[1] We should note that enforcement of building codes, the responsibility for which falls to local government planning departments, is a potentially time-consuming and expensive undertaking. Because of the time and expense required, it is generally recognized that code noncompliance is an issue. See, for example, Yang (2005).

[2] Despite the title and open membership, the ICC is an American institution. No other countries make direct use of the ICC codes, though many countries use them as a reference for their own code design.

[3] The ICC also issues many other building codes covering issues such fire safety, plumbing, mechanical and electrical systems, etc.

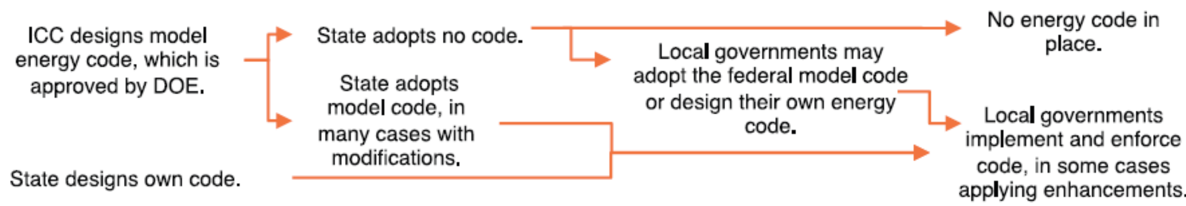

Figure 2. The code adoption process

The U.S. Department of Energy (DOE) analyzes each new model code to determine whether it is expected to save energy compared to its predecessor and publishes its evaluation. DOE's Building Energy Codes Program (BECP) then promotes the model code to the states and provides financial and technical assistance for state efforts to adopt, enforce, and assess compliance with these model codes. However, the federal government has no authority to directly regulate building energy efficiency in any state or local jurisdiction.[4]

The states do have this authority, and as of mid-2011 40 of the 50 states have adopted a statewide residential building energy code. When a new model energy code is issued and DOE determines that it will save energy, states are required to assess whether the code is appropriate in their context, though they are not required to adopt it. Most states have adopted some version of the IECC, often with a handful of stipulated revisions to better adapt it to the particular state setting. Four states – California, Florida, Oregon, and Washington – have designed and adopted state energy codes that are not closely related to the IECC. As of mid-2011, according to BECP, ten states have declined to adopt a binding statewide code, though some of these states promote codes and offer support to local governments that wish to adopt them or to builders who comply on a voluntary basis.[5]

Local governments must apply the statewide code. They also have the authority to adopt energy codes themselves, and in some cases do so. A few municipalities have also adopted more stringent provisions than the statewide energy code, even where one is present.

2.2 History of Code Creation and Adoption

In the early 1970s, some states began implementing building energy codes. The first code to see widespread adoption was the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 90-75, issued in 1975 and backed by the Council of American Building Officials (CABO) in 1977 following a public hearing and revision process sponsored by the Energy Research and Development Administration (a predecessor to DOE). This code was updated in 1980 as Standard 90A-1980. It appears that most states had adopted a version of these codes by the time the first national model code was adopted in 1992 (Heldenbrand (2001)).

The Energy Policy Act of 1992 created the BECP and mandated DOE's role in the development of model codes and in supporting state adoption. Since the program's inception, the DOE has adopted codes designed by building associations comprised of government and private actors. The first residential model code was the 1992 Model Energy Code (MEC) issued by the CABO. Updates were issued in 1993 and 1995. CABO then merged with several other buildings associations to form the ICC in 1998. The ICC issued the first IECC in 1998, with updates in 2000, 2003, 2006, and 2009. A new IECC will be adopted in 2012. The ICC has also issued occasional supplements to the code.

[4] The federal government can regulate federal buildings and manufactured housing (known as mobile homes).
[5] The BECP maintains a map indicating the residential building energy code status of each state at http://www.energycodes.gov/states/ maps/residentialStatus.stm.

As shown in Figure 3, the 1992 MEC is more stringent than Standard 90A-1980; engineering estimates suggest it should save 5% of energy use in a typical home relative to the Standard. Post-1992 updates to the model code have had relatively little energy saving impact up until the 2009 code, which represents a substantial tightening of the requirements. Unfortunately, energy consumption data are not yet available for the years since the 2009 code was adopted.

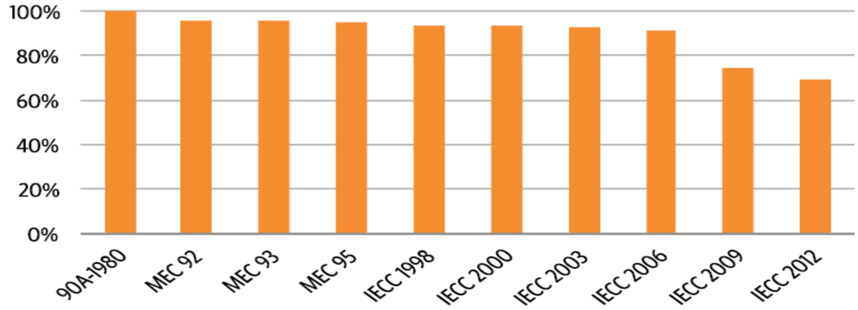

Figure 3. Projected impacts of building codes relative to baseline.

Most states have adopted some version of the IECC or the MEC. However, many lag years behind the current model code (see Figure 4).[6]

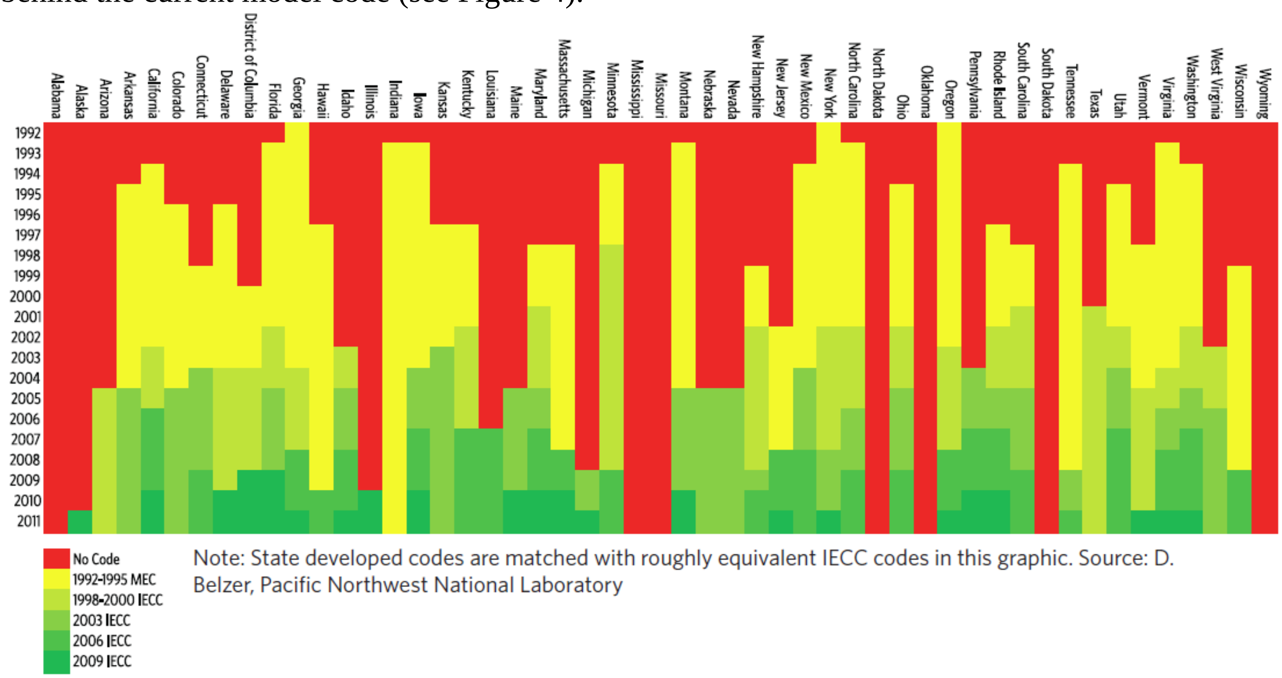

Figure 4. Building code stringency

2.3 Code Provisions and Applicability

[6] The data used to generate the figure were developed by Pacific Northwest National Laboratory (D. Belzer, personal communication, 28 July 2011). Where state-developed codes are in place, they are designated by the model code deemed most closely equivalent. Some states that do not have statewide codes were judged to have effectively adopted state codes due to local action, and thus appear as having codes in this figure.

Broadly speaking, the IECC residential code places requirements on the building thermal envelope and heating, cooling, and water heating systems (such as piping and ductwork). The code does not directly regulate[7] the energy performance of appliances themselves; devices such as furnaces, air conditioners, refrigerators, and water heaters are regulated by DOE's Appliances and Commercial Equipment Standards Program. However, codes prior to the 2009 IECC allowed tradeoffs between heating, cooling, and water heating equipment and other code requirements (see the performance compliance method below). The thermal envelope provisions set various requirements for R-values for insulation, U-factors for windows, and solar heat gain coefficients, which vary by climate zone.[8] Other provisions include air tightness requirements and insulation requirements for ducts and pipes.

The IECC applies to new residential construction[9] as well as to some alterations of existing structures. There are a number of exceptions for simple alterations, and even non-exempt alterations only trigger the code for the altered space, not the entire housing unit. Unfortunately, reliable data on housing alterations are unavailable. In this analysis we assume codes save energy only through their impact on new housing units.[10]

To comply with the IECC, one may choose either the "prescriptive" or "performance" pathway. For the prescriptive pathway, one may either satisfy all provisions individually or choose a total building approach that calculates the U-factor of the entire building thermal envelope while fulfilling other requirements individually. The performance pathway uses simulated building performance software to calculate the annual energy cost of the building as designed, ensuring that it is less than or equal to that of an equivalent building built in accordance with the individual provisions. DOE manages the development of the RESCheck software tool, which is approved by most states for total building U-factor calculations. While RESCheck is not a total building simulation, it does provide an approximate building-wide calculation that some states have approved for the performance path. State or local code officials are responsible for approving other building simulation software for performance path determinations.

In model codes prior to 2009, installing a high-efficiency furnace meant the insulation requirements for the remainder of the building were reduced. The 2009 IECC eliminates the ability to trade envelope requirements against unit performance. Many other codes, in U.S. states and overseas, continue to allow such tradeoffs.[11]

3 Existing Work

Even though building energy codes have existed in the U.S. for almost 40 years, evidence of their effectiveness based on actual energy consumption data has only recently begun to emerge. Most estimates of code impact that we have found use building energy simulations to calculate the difference between a typical unit's energy consumption under the new code and under the previous code. They

[7] Some code editions include minimum performance requirements for heating, cooling, and water heating equipment; however, these provisions match the prevailing appliance standards.

[8] R-values and U-factors are used to measure thermal resistance in insulation and windows, respectively.

[9] The residential portion of the IECC applies to all residential buildings under four stories in height. Taller residential buildings are regulated by commercial building codes. We omit buildings with more than five housing units from our analysis to account for this fact, but doing so does not substantially affect the results.

[10] Most existing estimates make this assumption as well. Two exceptions are Alliance to Save Energy (2010) and Wilcox (2007). In these studies, however, only 15 to 20% of savings come through alterations to existing buildings, so their work provides some justification for focusing on new build impacts.

[11] Examples: In addition to previous versions of the IECC, which are still in use in many states, the current version of California's Title 24 code (which is not substantially based on the IECC) allows these tradeoffs in the performance path, as does the German energy code.

then multiply this amount by the total number of units constructed under the new code to estimate total code savings.[12]

Reasons to expect that end use energy savings caused by the code might differ from engineering estimates include:

- *Code compliance.* Engineering calculations implicitly assume that code compliance is perfect. In fact, many studies (see Yang (2005) for a summary) have shown that compliance is far from perfect. Moreover, even where there is apparent compliance, mis-installation or improper maintenance can reduce the energy-saving impact of code measures.
- *Non-additional code provisions.* These calculations assume that the energy-saving measures required by the new code would not have been undertaken without the code. This may not always be the case; for example, technological improvements might lead to energy savings even if the code did not require them.
- *Rebound effect.* An improved building envelope makes it cheaper to heat and cool, as less conditioned air is lost to the environment. As a result, building occupants may increase their use of space conditioning to some extent, offsetting some of the energy savings the envelope generates. Building energy simulations do not factor in behavioral responses of this kind.
- *Spillover effect.* Building codes may affect building practices regionally and lead to improvements in practice outside of their jurisdictions. If this is the case, our model will underestimate the effect of energy codes, as it will be comparing them to a baseline that is also experiencing some energy savings from the code. These spillover benefits will not be captured by our estimates.

Our econometric analysis embeds these factors. Our estimate yields the net impact of the codes; however, it is silent on the relative impacts of these factors.

The earliest econometric study we are aware of that tests the impact of building energy codes with energy use data is Jaffe and Stavins (1995). The authors use several variables, including building codes, to explain the level of installed thermal insulation in new home construction in the U.S. They find that the studied codes do not have a statistically significant effect on insulation levels. Their explanation is that most codes in their study (all of which predated the 1992 MEC) were likely non-additional in the sense that standard insulation practice already met or exceeded them. Arimura et al. (2009) study the impact of utility demand-side management on state electricity consumption over a similar time frame to our study and include building codes as a controlling variable. Their best estimate of code impacts is a very small electricity savings.

On the other hand, three recent studies focus on codes and show statistically significant impacts. Jacobsen and Kotchen (2010) study the impact of a single change to the Florida state code on electricity and natural gas consumption using household-level billing data. They show that per-residence electricity and natural gas consumption decreased by approximately 4% and 6% respectively after the implementation of the code, and that these changes are not explained by pre-existing trends. Costa and Kahn (2010) use household-level data in a California county to show that building codes have been associated with reduced residential electricity demand. They do not estimate effects on natural gas consumption. Aroonruengsawat et al. (2009) is the closest cousin to our study. The authors use variation in code adoption by state over time to identify the effect of codes on residential electricity consumption in the U.S. They find that building energy codes are associated with a 2 to 5% reduction in per capita residential electricity consumption. They also show the level of effort states exert to implement and enforce code compliance, as measured by the American Council for an Energy Efficient Economy (ACEEE)'s State Energy Efficiency Scorecard, is useful in explaining code impacts: states with a better

[12] Analyses using variants of this calculation include Alliance to Save Energy (2010), Wilcox (2007), and Pacific Northwest National Laboratory (2009).

score show greater electricity savings. They do not estimate code effects on the consumption of natural gas or other fuels.

4 Study Methods and Data

This study estimates the effect of building energy codes on residential energy consumption and greenhouse gas emissions at the state level. We examine code impacts on electricity, natural gas, and other fuels individually, as well as impacts on total final and primary energy consumption and greenhouse gas emissions. In order to isolate the impact of the codes, we control for other important factors affecting building energy consumption, such as energy prices, economic conditions, weather, climate, and residential construction rates. Our model also accounts for factors that do not vary across states, such as federal policy or nationwide trends. Our data cover the 48 continental U.S. states and the years 1986 through 2008.

To put our strategy to work, we need to know when each state adopted each version of the code. Code adoption data are based on a database compiled by staff involved in the Department of Energy's Building Energy Codes Program at the Pacific Northwest Laboratory.[13] The data indicate when each state adopted each federal model code, beginning with the 1992 MEC. Where states develop their own codes, the PNNL data match the state code with the most similar national model code at the time.

Combining data on new construction and code status, we measure the fraction of occupied units in a given state built under an energy code at least as stringent as the 1992 MEC. This is the primary variable of interest for our analysis. If building energy codes save energy, states with a larger percentage of housing stock built under a code should consume less energy per housing unit, holding all else equal. We regress this variable on various measures of residential energy use in each state in each year. Our model controls for the other variables discussed above as well as for nationwide time trends and state-specific factors that might distort our result.

Our base analysis treats as equal all codes that are at least as stringent as the 1992 MEC, up to and including the 2006 IECC, therefore estimating the average effect of all these codes as a group. This choice significantly increases the statistical power of our approach–in other words, our ability to distinguish the effect of the codes from other trends. As Figure 5 shows, our data include a fairly small number of years during which a post-1992 code was in place. The small number of observations reduces our power to estimate the impacts of each code separately.

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[13] Data supplied by D. Belzer, PNNL. In addition to work by staff at PNNL, the code adoption dates are also based upon newsletters published by the Building Codes Assistance Project (BCAP). See website http://bcap-energy.org/.

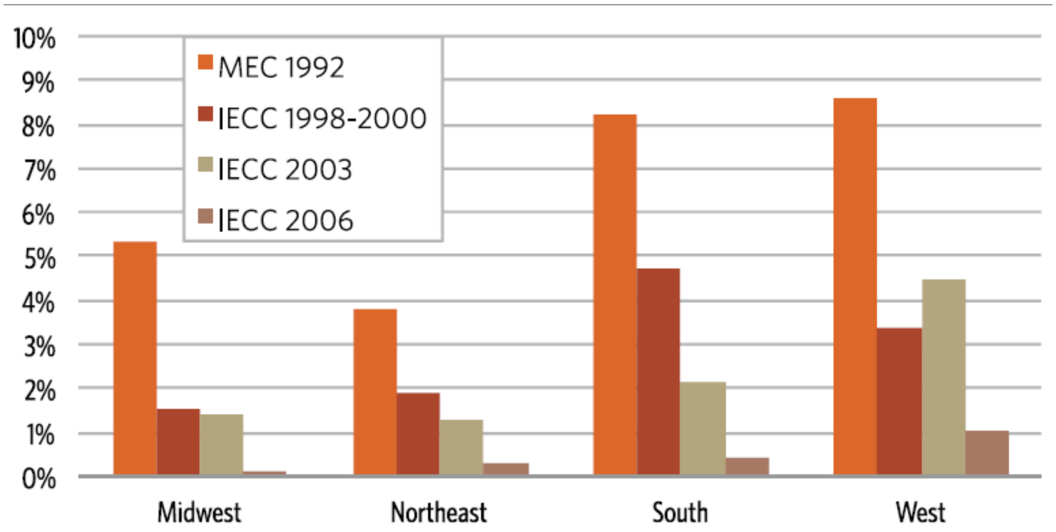

Figure 5. Percent of occupied units under each code: 2008 regional average

We should note that there are several reasons to believe that the codes adopted by different states would have different impacts. First, model codes have become somewhat more stringent over time. According to engineering simulations, however, the differences between the codes we study are not dramatic. Figure 3 shows that the modeled final energy savings of the 1992 MEC relative to the presumed Standard 90A baseline is about 4 to 5%, and that subsequent codes through the 2006 IECC improve on the 1992 MEC by about the same amount in total.[14] Second, states often adopt model codes with amendments, meaning that two states adopting codes based on the same model code are likely not adopting the exact same provisions. We understand from conversations with buildings experts that these changes tend to be minor, although some may have implications for our fuel-specific results.[15] We therefore do not treat them explicitly, so our estimates measure the average effect of all code versions. Third, the level of effort states devote to promoting code compliance through training and enforcement activities varies. Aroonruengsawat et al. (2009) show that states scoring better on building energy code compliance efforts in ACEEE's Energy Efficiency Scorecard save more energy through their codes. We may explore such effects in a future extension of this analysis. In the end we are confident that none of these issues invalidates our choice to pool all the codes for this study.

5 Estimated Code Impacts

We estimated two models of code effect. The first (Model 1) measures the average impact of all building energy codes at least as stringent as the 1992 MEC. The second (Model 2) measures the average impact of all state codes that are based on a national model code. Four states in our dataset– California, Florida, Oregon, and Washington–have developed their own codes that are not based on any version of the MEC or IECC, so they are omitted in Model 2.

Figures 6 and 7 present the average estimated per-household impact of building energy codes on four energy use measures: total primary energy, natural gas, primary electricity, and other fuels. As explained earlier, primary energy is the total household energy footprint.

[14] The considerably more aggressive 2009 and 2012 codes provide additional evidence that we should view the post-1992 changes through 2006 as relatively minor.

[15] Specifically, at least a few states have adopted provisions limiting the use of electric resistance heating, an issue we may address in future work.

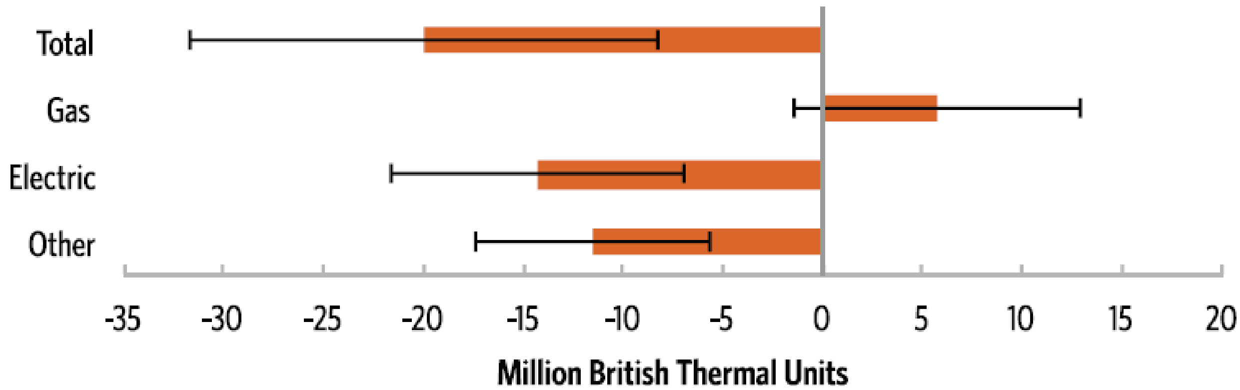

Figure 6. (Model 1) Average estimated annual impacts of building energy codes on household primary energy use

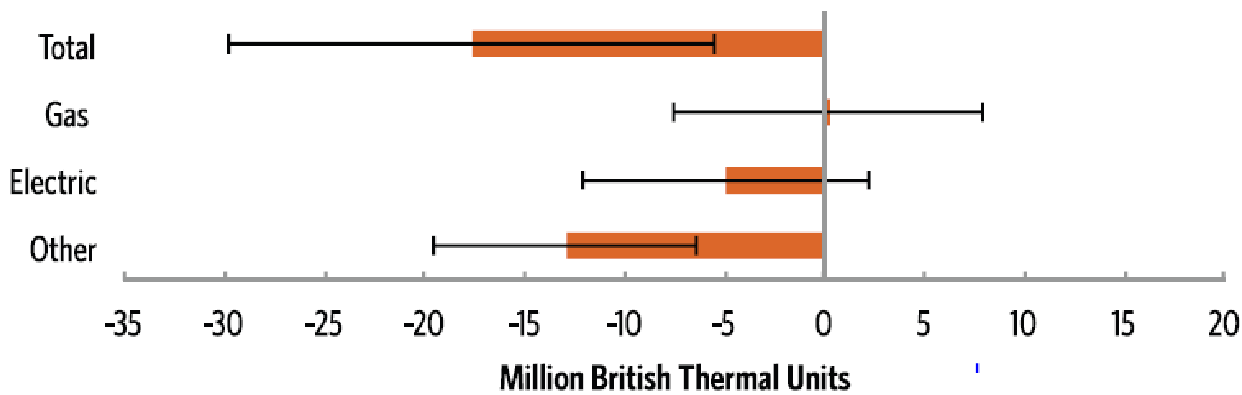

Figure 7. (Model 2) Average estimated annual impacts of model code-based building energy codes

As shown, the presence of an energy code is associated with lower primary energy use per household. The codes are also associated with decreased consumption of electricity and other fuels[16] and equal or slightly increased consumption of natural gas. We estimate that the energy savings correspond to a 16% (3.7 tonnes) reduction in greenhouse gas emissions[17] per household per year in Model 1 and an 11% (2.6 tonnes) reduction per household per year in Model 2.

Our overall results are similar for the two models. However, Model 1 shows a large, statistically significant decrease in electricity use and a small increase in natural gas use, while Model 2 shows a smaller decrease in electricity use and essentially no change in gas use. We must therefore be cautious in ascribing effects on these two fuels to the model codes; it appears that the four state-developed codes may have rather different impacts. We discuss this issue further in Section 5.2 below.

5.1 Impacts on Primary Energy Use

We find that the energy codes studied are saving energy in residential buildings. Model 1 suggests 11% primary energy savings, while Model 2 suggests 10%. Both results are statistically

[16] Primarily fuel oil, but also includes wood, kerosene, coal, and propane
[17] We calculate greenhouse gas emissions changes from natural gas, electricity, and fuel oil only. We aggregate fuel-specific CO_2-equivalent emissions factors for CO_2, CH_4, and N_2O.

significant. Aggregating the Model 1 savings estimate over all code-built housing units in 2008, the final year of our data, indicates that the studied codes saved 28 trillion BTUs of energy in that year. This represents 1.3% of U.S. primary residential energy use in 2008.

Our best estimates of the effect of codes on primary energy consumption are higher than simulations suggest. Combining data on the number of units constructed under each code with simulated estimates from Pacific Northwest National Lab, the average home built under a code during the period studied would be expected to reduce its energy consumption by 5%. While our estimates are higher, 5% is contained in the confidence interval of both estimates.[18]

There are several factors that could help explain why our estimates of energy savings per housing unit are higher than the engineering estimates:

- Our current model does not control for other policy (such as appliance standards and utility DSM programs) that would be expected to reduce household energy use. If states[19] tend to adopt these other measures at the same time as they adopt building energy codes,[20] our current model would attribute some of the impacts of these programs to codes.
- Due to data limitations, it is likely that we excluded some housing units from our count of code-built units. In order to eliminate large buildings covered by commercial codes, we dropped all units in buildings with more than five units. This means we are attributing overall energy savings from the code to a smaller number of units, increasing the per-unit effect size. When we run the same analysis with all of these units included, our per-unit primary energy savings estimate in Model 1 drops but only to 9%. This value provides a robust lower bound estimate, as this model certainly overestimates the number of units affected by the code. The number of code units assumed should have no effect on our calculation of total code savings, however.
- Relatedly, we do not account for the savings codes may achieve through retrofits of existing buildings. As discussed in Section 2.3 above, some existing analyses suggest that 15 to 20% of code impacts may come through retrofit. If true, our estimates of primary energy impacts per new housing unit are about 2% too high. Again, our total energy savings estimates should still be accurate.
- In constructing the engineering estimate, we use Standard 90A-1980 to estimate baseline energy use. If instead some of these states had no code, or codes inferior to Standard 90A-1980, prior to adopting a post-1992 MEC code, then the baseline energy efficiency in our data is worse than the engineering estimate baseline, meaning our results would not be comparable to the engineering estimates. This factor does not affect the accuracy of our estimate, but rather the validity of the comparison to the engineering estimate.

On the other hand, one factor suggests that our results may miss some energy savings created by the codes. When codes advance building practice in jurisdictions that adopt them, there is reason to expect that these advances may "spill over" into other states as builders adapt and learn. Our models do not account for such effects, and thereby undercount savings in two ways. First, savings in states without codes are not credited to the codes by our model. Second, non-code states in our models form the baseline off of which code savings are estimated. If the energy use of these states embeds some savings, this baseline is more efficient than a true no-code baseline, and it therefore appears that codes are saving less than they really are.

[18] 5% savings is within the 95% confidence interval in both model. The 5% estimate is also within the 90% confidence interval in Model 2, though it is just outside the 90% confidence interval in Model 1.
[19] Federal regulatory activity would not be an issue here, as our fixed effects econometric model controls for changes that affect all states at the same time.
[20] Arimura et al. (2009) show that building code adoption and utility DSM expenditures are slightly correlated in their dataset, which is similar to ours.

Given the uncertainty in our model as well as the factors discussed in the previous paragraphs, we view our results as consistent with the engineering estimates, suggesting that, if anything, the engineering estimates are too low.

5.2 Fuel-Specific Impacts

Use of "other" fuels –primarily fuel oil– has fallen in both models; these results are statistically significant. Model 1 shows a statistically significant decrease in electricity use of approximately the same percentage as the overall decrease in energy use. Model 2 shows a smaller effect on electricity that is not statistically significant. Model 1 suggests that natural gas use has risen, though the finding is not statistically significant; Model 2 shows no effect on natural gas use.

In interpreting these results, we note that each is a composite of two effects: a general decrease in energy use and, potentially, a shift in fuel choice. This is particularly notable for electricity, which comprises a large share of residential primary energy in the U.S. When we predict the share of energy use for each fuel with our regression model, we learn that the electricity share is unchanged in Model 1 and actually goes up in Model 2. Gas shares go up and "other" shares down in both models.

As noted in section 2.3, the model codes in this study allow energy-saving tradeoffs between heating and water heating units and the building envelope where the performance pathway is elected. These provisions specifically encouraged natural gas heating and water heating and electric heat pumps, while discouraging electric resistance heat. The increases in natural gas use that we observe are consistent with this provision, while the decrease in use of other fuels suggests substitution away from them and towards natural gas or heat pumps.

As for electricity, the net impact of the code provisions on fuel choice is ambiguous, as they encourage heat pumps while discouraging electric resistance heating. Model 1 (all building energy codes) shows a stronger reduction in electricity use than Model 2 (codes based on national model only). This suggests the four state-developed codes might include stronger provisions to discourage electricity use. In fact, the three West Coast states have code provisions that discourage electric resistance heat. Heating is a relatively small contributor to building energy consumption in the fourth state (Florida), so we would expect little energy impact from any heating-related fuel-switching that the codes did motivate.

5.3 Impacts on Greenhouse Gas Emissions

Both models show substantial and statistically significant reductions in greenhouse gas emissions associated with codes. Model 1 estimates a 16% reduction in emissions per household, while Model 2 estimates 11%. The fact that Model 1 estimates greater greenhouse gas reductions can be traced to the fuel-specific impacts. Model 1 (and by implication the four states excluded from Model 2) shows more natural gas use and less electricity use in code households. Burning natural gas in the home is considerably less emissions-intensive than consuming electricity from the current U.S. generation mix.

Taking the per-household reduction estimate noted under Model 1 above and multiplying it by the 14 million households built under one of the studied codes in 2008, we estimate that emissions were 52 million tonnes CO2-equivalent lower in 2008 than they would have been had in the absence of energy codes. This is about 1.8% of U.S. greenhouse gas emissions from residential buildings in 2008 (U.S. Department of Energy (2010)). As building energy codes become stricter and the proportion of residential buildings built under modern codes rises, these savings can be expected to increase significantly.

6 Policy Implications

We highlight four points for policy that follow from our study.

First, building energy codes clearly appear to be successful in saving energy in residential buildings. Notwithstanding potential complications created by noncompliance, non-additional codes, and rebound effects, our models show savings with a high level of certainty. The average per household energy savings (measured in either final or primary terms) delivered by energy codes in the period from 1992-2008 are on the order of ten percent relative to prior practice.

Second, building energy codes have been effective in reducing greenhouse gas emissions from buildings. Our model estimates that houses built under energy code regimes were associated with 16% lower greenhouse gas emissions, yielding a 1.8% overall reduction in residential building emissions in 2008.

Third, our results suggest that the studied codes delivered savings that are similar to those estimated by engineering models. Our estimates based on *ex post* energy use data are somewhat higher, though several factors noted in section 5.1 may explain this discrepancy. Moreover, the uncertainty in our estimates of code impacts means they are not inconsistent with the engineering estimates. Coupled with other recent findings (Aroonruengsawat et al. (2009) and Jacobsen and Kotchen (2010)), our results suggest that none of the above-noted complications is significant enough to warrant a systematic downward adjustment to modeled savings.

Fourth, code provisions affecting fuel choice– through the use of the performance pathway for compliance or through state-specific provisions– appear to have had an impact. The compliance pathway provisions are probably efficient policy in the short run, but may be less so in the long run. A unit that takes advantage of these tradeoffs may install a less efficient envelope than would otherwise be allowed. Envelopes are a more permanent building feature than heating, cooling, or water heating units. Therefore, these buildings will likely be less efficient than they otherwise would be once these original units have been replaced. Moreover, as the U.S. electric supply is decarbonized, natural gas units will deliver fewer emissions savings. Policymakers will need to balance these short run and longer-run impacts. We note that the 2009 IECC no longer allows these tradeoffs, although some states (e.g., California) and nations (e.g., Germany) do.

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