How Much Energy Do Building Energy Codes Really Save?
Evidence from California

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Abstract

Construction codes that regulate the energy efficiency of new buildings have been a centerpiece of US environmental policy for 40 years. California enacted the nation's first energy building codes in 1978, and they were projected to reduce residential energy use—and associated pollution—by 80 percent. How effective have the building codes been? I take three approaches to answering that question. First, I compare current electricity use by California homes of different vintages constructed under different standards, controlling for home size, local weather, and tenant characteristics. Second, I examine how electricity in California homes varies with outdoor temperatures for buildings of different vintages. And third, I compare electricity use for buildings of different vintages in California, which has stringent building energy codes, to electricity use for buildings of different vintages in other states. All three approaches yield the same answer: there is no evidence that homes constructed since California instituted its building energy codes use less electricity today than homes built before the codes came into effect.

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> New building codes will reduce the energy "used in typical buildings by at least 80 percent."
>
> —California Energy Commission, 1979

> "New houses in California now use one-fourth of the energy they used 25 years ago."
>
> —Tom Friedman in the *NY Times*, April 13, 2014

It seems like a straightforward empirical question: How much energy has been saved by state and local regulations that require newly constructed homes to meet energy-efficiency building standards? When regulators first began enacting the codes, they projected enormous savings—like the 80 percent reductions promised for California's nation-leading late-1970s building codes. Today, advocates of tightening those standards claim that those initial promises have been realized.

But answering that question requires knowing how much energy would have been used in the absence of the building codes, a far more difficult calculation than is sometimes suggested. We cannot simply compare energy use by residents of efficient and inefficient buildings because people with larger energy needs may select energy-efficient homes. We cannot just take engineers' *ex ante* estimates of how much less energy a given building will use because that ignores the *ex post* response by the building's occupants. And we cannot easily compare jurisdictions with more and less strict energy-efficient building codes because those jurisdictions presumably chose to enact the codes based on the energy-using characteristics of their residents. These problems—the selection of occupants into efficient homes, the behavioral response to having an efficient home, and the endogeneity of the policies—represent some of the most difficult problems in empirical microeconomics.

Figure 1 illustrates the challenge. It describes the *current* average annual household electricity use in California, according to when the home was constructed. Homes built recently are not using 80 percent less electricity than homes built before the California standards were first enacted in 1978; they are using more. The comparison is not fair, of course, because homes built more recently are larger, have more occupants, and are in hotter parts of the state. Controlling for those home features, and for the selection of people with high energy demand into recently-built homes, is the objective of this paper.

The stakes involved are far higher than whether or not a local ordinance works as promised. Energy-efficiency policies like California's have become the centerpiece of US climate policy. President Obama said in his June 2013 climate speech at Georgetown University that efficiency standards "will reduce carbon pollution by at least three billion tons."[1] More than one-third of the greenhouse gas emissions reductions targeted by Massachusetts's Global Warming Solutions Act of 2008 are projected to come from energy-efficiency improvements to buildings and appliances. Nearly 20 percent of the reductions in California's 2006 Assembly Bill 32 come from new energy-efficiency standards for buildings and utilities.[2] And half of the projected carbon emissions reductions from the US Environmental Protection Agency's proposed Clean Power Plan for existing electric power plants come from demand-side energy-efficiency improvements. The United States is putting much of its climate effort into this one policy.

Americans now have four decades of experience with energy-efficiency standards for buildings. But attempts to measure the effect of building codes or other efficiency mandates largely fail to address any of the key empirical challenges: selection, behavioral response, or policy endogeneity. Approaches have included engineering analyses that assume energy-efficient appliances and buildings will be used no differently from inefficient buildings and appliances; regressions of average household energy use on measures of local energy-efficiency policies, without accounting for the endogeneity of those policies; decomposition analyses that control for some changes over time in some observable correlates of energy consumption and attribute unexplained declines in energy consumption to efficiency; quasi-natural experiments that examine energy consumption in buildings constructed before and after a change in local building codes.

I address all these problems—selection by tenants, differential use, and policy endogeneity—in three ways. First, I use the California Energy Commission's Residential Appliance Saturation Study (RASS), conducted in 2003 and 2009, to estimate energy use as a function of resident demographics, building characteristics, and year of construction. If building codes save energy, otherwise similar homes built more recently under stricter standards should use less energy. Though this first approach still ignores the potential selection of tenants into efficient or inefficient buildings, I control for a richer set of occupant and house characteristics than has been possible before.

The second approach focuses on the sensitivity of electricity use to temperature changes. I match the monthly utility bills from the California RASS data with monthly temperatures in the households' zip codes and examine the degree to which electricity use increases with temperature. If building codes work as promised, during months that are hotter than usual, electricity use for air conditioning should increase less steeply in buildings constructed under more stringent standards.

Finally, the third approach compares California to the other 49 US states. The California Energy Commission established some of the nation's first and most stringent building energy-

[1] www.whitehouse.gov/the-press-office/2013/06/25/remarks-president-climate-change.
[2] Massachusetts Secretary of Energy and Environmental Affairs, 2010, p. ES-6. CARB, 2008, p.17.

efficiency standards in 1978. Those codes have been strengthened every few years since then, and California consistently appears at the top of rankings of state energy-efficiency regulations.[3] If the building codes have been as effective as promised, new houses in California should use less energy than older houses, and that gap should be larger in California than in other states. For this third approach, I use a different dataset, the US Department of Energy's Residential Energy Consumption Survey (RECS), conducted every three or four years from 1993 to 2009.

All three approaches yield the same answer: after controlling for the size and location of homes, and the income, age, number, and education of the occupants, there is no evidence that homes constructed since California instituted its building energy codes use less electricity today than homes built before the codes came into effect.

What These Findings Do Not Mean

Because I recognize the potential for controversy, let me be clear about what this paper does not say. Nothing in here should be taken as evidence that energy-efficient building codes are bad policies—only that states should not be credited with saving the amount of electricity and carbon dioxide emissions promised when those codes were enacted.

One reason that new and old buildings might use similar amounts of energy today is that owners of older homes have taken steps to increase the energy efficiency of their homes: upgrading their heating and cooling systems, replacing windows, or adding insulation. If homeowners would eventually increase the energy efficiency of their buildings anyway, building codes might save homeowners that expense but should not be credited with reducing energy consumption relative to a world without the codes, at least not for long. Another reason that new and old buildings might use the same electricity today is that homeowners respond to the lowered cost of lighting and air conditioning by using more. In that case, the codes may make homeowners better off but not save as much energy as promised. In sum, what follows should not be interpreted as an indictment of building energy codes, only an indictment of relying on their forecasted energy savings and carbon reductions as a part of environmental policy.

The Evidence So Far

Before describing the research to date on this important question, it is worth taking a moment to look at the policy in detail. Table 1 reproduces one page from a detailed cost–benefit analysis done by the California Energy Commission in support of their 1980 Building Standards Project. The report contains 48 separate analyses, one each for detached, attached, and multi-family homes in each of 16 different parts of the state. The example in Table 1 is for single-family detached homes in Sacramento. Column (1) reports the expenditures on various energy-related home construction features without the

[3] American Council for an Energy Efficient Economy (ACEEE) www.aceee.org.

new California building codes—the "business-as-usual" costs. Column (2) reports the costs associated with the building codes. I've added column (3), the difference between the two, demonstrating that the California codes add $8,000 to the construction cost of a new home, about 10 percent of the median 1980 California home price.

The bottom of Table 1 reports estimates of the total energy consumed by the sample home under each scenario. The new building codes are projected to reduce energy consumption by 77 percent, immediately justifying the $8,000 expenditure.

Have energy codes like those described in Table 1 lived up to their promise, and do they save energy in the long run? Given the importance of this question and the challenges to answering it, a wide variety of strategies have been taken. Each has its own merits and shortcomings.

Most assessments of the energy savings from building codes rely on engineering analyses. The California Energy Commission estimated that its residential building codes saved 7,039 gigawatt hours of electricity in 2012, or 7.8 percent of total residential demand.[4] This calculation presumes the building codes are enforced, the savings predicted by engineers are realized, and there is no behavioral response. But there is reason to doubt all three assumptions. Jaffe and Stavins (1995) show that actual levels of insulation in homes did not increase as required by building energy codes. Metcalf and Hassett (1999) show that when insulation is installed, the realized savings fall short of engineers' predictions. And in theory, when building codes reduce air conditioning costs, people may be more inclined to turn the temperature cooler or leave their systems running while they are away from home.

As an alternative to engineers' predictions, some have regressed aggregate local energy consumption on energy prices, weather, population demographics, and some proxy for energy-efficiency policies. Haeri and Stewart (2013) use lagged expenditures on utility energy-efficiency programs as the measure of policy and conclude that the $7 billion California utilities spent on energy efficiency reduced electricity consumption by 6.5 percent, at an average cost of $0.03 per kilowatt hour. Horowitz (2007) groups US states into quartiles based on the US Energy Information Administration's reported cumulative energy savings from demand-side management programs and finds that states with the strongest commitments to energy efficiency saw a 9.1 percent *increase* in residential electricity use relative to states with weaker commitments. These types of studies typically ignore the potential endogeneity of the key policy variables. Utilities expecting faster growth in electricity demand or with conservation-minded constituents may invest more in energy-efficiency programs.

One clever version of this regression-based approach that does address policy endogeneity is Aroonruengsawat et al. (2012). They regress per capita residential electricity consumption in US states on energy prices, weather, and the share of housing stock built since each state's initial implementation of energy-efficient building codes. Because building code implementation is endogenous, the authors

[4] California Energy Commission, 2014 (Table 2 for 2012 total and Table 25 for savings).

instrument for it using lagged heating and cooling degree days, on the theory that particularly harsh winters or hot summers spurred states to enact energy-efficient building codes. They find that states where a higher fraction of housing stock was built after building codes were enacted use less energy per capita, and that those savings amount to between 2 and 5 percent of nationwide residential energy use.

An altogether different strategy decomposes changes in energy demand into those components due to exogenous trends and examines the remainder as a possible outcome of efficiency programs. Studies differ in what changes they control for as not being related to energy efficiency. Metcalf (2008) shows that US energy consumption per dollar of GDP declined by 47 percent from 1970 to 2003, about one-quarter of which can be explained by changing personal consumption expenditures, value added by businesses, and vehicle miles traveled. The remaining three-quarters he ascribes to energy efficiency, though he is using a broad definition of efficiency that includes other demographic changes and reduced consumption.

Hojjati and Wade (2012) control for shifts in the size and mix of housing types, regional distribution of households, and weather. Even after accounting for those trends, from 1980 to 2005, US household energy consumption per square foot decreased by 38 percent, which the authors ascribe to "*prima fascia* evidence of the efficacy of … energy-efficiency … standards and programs" (304). But that 38 percent decrease is still at least partly attributable to trends their decomposition analysis omits. For example, during that period, the average household size declined by 7 percent, driving down energy consumption per household but driving up energy consumption per person.

The best approaches use household-level data and focus on particular programs. Davis et al. (2014) evaluate a Mexican program that subsidized consumers replacing old refrigerators and air conditioners with newer and more energy efficient models. Households that replaced their refrigerators did use less electricity, but only one quarter of the amount predicted by the policy's proponents. And households that replaced air conditioners used *more* electricity after the replacement than before. Grimes et al. (2014) study a New Zealand program that retrofitted 12,000 homes with insulation and clean heat sources. They find that homes retrofitted with insulation reduced energy consumption by one percent, while the homes retrofitted with clean heat used more energy.

The ideal approach would be to randomly assign residents to energy-efficient and inefficient homes. Though that is impractical, Fowlie et al. (2014) try the next-best strategy. They randomly encourage a subset of eligible homeowners to take up Michigan's 2009 Weatherization Assistance Program, then use that random treatment as an instrumental variable, comparing energy use by households that did and did not receive the encouragement. They find that weatherized homes do use less energy but that the savings are only about one third of what energy auditors predicted for those very same homes. Moreover, despite in-person visits and phone calls, personal assistance with applications, and offers of free energy audits and $4,500 worth of weatherization, only 5 percent of households followed through with the program. As a result, even the random encouragement design turned out to be a relatively weak instrument.

One final approach, and the one most similar to the one I take here, is to seek out a change in a particular building code and examine energy use by homes constructed before and after the change. Jacobsen and Kotchen (2013) compare the utility bills in 2004–2006 for homes in Gainesville, Florida, built just before and after the city tightened its building energy codes in 2002. They find that homes built after the change use 4 percent less electricity and 6 percent less natural gas. One concern their paper cannot address is that the new and old homes may differ in ways that are correlated with energy consumption. Their data contain no information about the number or characteristics of the homes' occupants. And their strategy cannot distinguish building age from year of construction. All the homes subject to the new building codes were recently constructed, conflating building vintage with building age.[5]

In what follows, I describe three separate approaches: (1) estimating annual electricity use today by California homes built at different times, controlling for home and occupant characteristics; (2) examining the sensitivity of monthly residential energy use in California to unusually hot weather for homes built at different times; and (3) comparing the difference between energy use in new and old homes in California to that same difference in other states. Before detailing those three approaches, I describe the data I use and discuss two issues: trends in electrification of heat and hot water, and the confounding effects of building vintage, age, and survey year.

Data and Two Often-Overlooked Issues

For this project, I use two separate main sources of data. The Residential Appliance Saturation Study contains detailed information about the buildings, occupants, and energy consumption of more than 22,000 California households in 2003 and another 26,000 in 2009. I focus on single-family homes with non-missing information about key home and occupant characteristics where I could match the household to energy billing data provided by the California Energy Commission. That leaves 7,400 homes in 2003 and 8,900 in 2009.[6]

As a comparison, I conduct the same exercise with a different data source. The Residential Energy Consumption Survey is a nationally representative survey of household characteristics and energy use conducted every three to four years by the US Department of Energy. The RECS does not publicly identify the state in which the house is located, but starting in 1993 it does identify California homes. I use the five surveys conducted from 1993 through 2009. Each reports the year the home was built as a range, and although the ranges differ somewhat in each survey, there is enough information to collapse the measures to identify the decade of construction for each home. I focus on the 2,000

[5] Costa and Kahn (2010) take a similar approach using a cross section of homes in one California county, and Kahn et al. (2014) explore a nationally representative cross section of 5,000 commercial buildings.

[6] More information about the RASS can be found at www.energy.ca.gov/appliances/rass. I obtained access to the monthly utility billing data for RASS households by an open records request to the California Energy Commission.

single-family California homes with non-missing information about critical house and occupant characteristics.

For the second empirical approach—examining the sensitivity of monthly electricity use to outdoor temperatures—I go back to the RASS data and match households by zip code to nearby weather stations. The monthly weather station data come from the National Oceanographic and Atmospheric Administration (NOAA).[7] The third empirical strategy compares California to other US states. For that, I turn back again to the RECS.

The Confounding Effects of Building Age, Vintage, and Survey Year

Even the best of the existing studies fail to account for one important determinant of energy efficiency: building age. The key distinction is between building age—how old the building is at the time of the survey—and building vintage—when the building was constructed. A building's vintage determines the stringency of the energy-efficiency regulations the builder faced, but in a cross-section of data building age and vintage cannot be separately measured. All 10-year-old buildings surveyed in 2009 were built in 1999. If homes become draftier with age, researchers may find that more recently constructed buildings use less energy and spuriously attribute that to stricter new building codes and energy efficiency. But repeated cross sections of data will contain 10-year-old buildings built in different years under different efficiency standards. That is one of the advantages of the empirical strategies that I take: I use surveys constructed from repeated cross sections.

Figure 2 plots electricity use by California households built just before and after the state tightened building codes in 2001, separately for the 2003 and 2009 RASS surveys. The lightly shaded bars show that in 2003, homes built under the 2001 building codes use 4.6 percent less electricity on average than homes built in the three years prior to those codes. But the darkly shaded bars show that six years later, in the 2009 RASS survey, that difference disappears. Something about the newness of the homes led them to use less energy, not the building codes when they were constructed. In fact, in the 2009 RASS survey it seems as though homes built in 2005–2008 use less electricity than those built in 2001–2004, although I suspect that if we resurveyed those homes today, we would again find no difference.

Table 2 examines this newness effect more systematically. It uses just the homes in the RASS built between 1998 and 2004—the left two pairs of bars in Figure 2. Column (1) regresses the log of annual electricity use on house characteristics and a dummy variable for the later vintage, using only the one cross section of data in the 2003 RASS. Homes built after the 2001 California building code change use 12 percent less electricity, suggesting the policy was effective. Column (2) revisits the question six years later using the 2009 RASS and finds no statistically significant difference between homes built before and after the 2001 building code change. Columns (3) and (4) of Table 2 repeat the exercise for the sum of electricity and natural gas, with the same outcome. Newly built homes use less

[7] www1.ncdc.noaa.gov/pub/data/cdo/documentation/GHCNDMS_documentation.pdf

energy because they are new, not because they were constructed to comply with stricter building codes.

Recall the example from Gainesville, Florida. That study found energy use in 2004–2006 to be lower for homes built just after Florida's 2002 building code change.[8] But that result confounds the age of the building with its vintage of construction. I suspect if we revisited those Gainesville homes today, 10 years later, we would find no difference in energy use for homes built before and after the 2002 code change.

As a curious parallel, this confusion between age and vintage was central to a key debate about immigrants' wages back in the 1980s. Chiswick (1978) and others inferred from cross sections of data that the wage-age profile for immigrants was steeper than for natives. Immigrants' wages appeared to grow faster with their ages, perhaps due to their work ethic or assimilation. But Borjas (1985) showed that this result was driven largely by the changing characteristics of people who immigrated to the United States—a cohort effect. Recent cohorts of immigrants have had less education and fewer skills. Thus in any cross section of data, younger immigrants have low wages and older immigrants have high wages, but those older immigrants would have had higher wages when they were young as well. Cohorts of immigrants in that debate are analogous to vintages of buildings in this one. Chiswick interpreted cross-sectional differences in wages to be an age effect, but Borjas shows it is was a cohort effect. Jacobsen and Kotchen interpret cross-sectional differences in residential energy use to be a vintage effect of building codes, but I believe it is an age effect.

What might explain the lower energy consumed by very new homes in Gainesville and California? Perhaps not all the occupants of the newest homes had completely moved in, or even been born at the time of the survey. New homebuyers may be conserving energy to help meet high payments on new mortgages. Perhaps the appliances are newer or not yet purchased and plugged in. Perhaps the air filters and ducts are cleaner, and the windows better-sealed and less drafty.

Whatever the explanation, by using repeated cross sections of California homes, I can distinguish between building age and vintage in several ways. First, the California Energy Commission issued its first sets of energy-efficiency building standards in 1978 and 1980. Presumably the newness effect has faded away by now for homes built before and after those regulations took effect. Second, I can control for the number of years the residents have lived at the address, separating the effect of a new owner from the effect of a new building.

But one tricky remaining problem involves simultaneously controlling for the year of the survey. In different years, homeowners could well consume different amounts of electricity. Appliances change and new ones become available, energy prices change, and people adopt different patterns of energy use. But the three variables—vintage, age, and survey year—are linearly related.

[8] See Figure 3 of Jacobsen and Kotchen (2013).

$$building\ age = survey\ year - building\ vintage$$

A regression of energy use on home characteristics cannot include all three covariates.

Figure 3 illustrates the problem using seven cross sections of national RECS data going back to 1987. From those data I constructed synthetic cohorts, grouping homes by building age and decade of construction. The figure plots electricity use by building age, separately for each vintage of construction, controlling for no other characteristics. Each line in Figure 3 represents a different vintage of homes, by decade of construction. Each dot on a line represents a different RECS survey, from 1987 through 2009.

Three features stand out. First, more recently constructed homes (higher lines) use more electricity. As I have already noted in other contexts, that may be explained by other home characteristics and is what this paper is in large part an attempt to explain. Second, the age-energy profiles are upward-sloping for every vintage. That could be the result of homes aging, or it could be the general time trend of increasing electricity consumption. Third, the age-energy profile is steepest for the very newest homes, those constructed in the 1990s and surveyed in the 1993 or 1997 RECS and those constructed in the 1980s and surveyed in the 1987 or 1990 RECS. This is unlikely to be the result of general trends in electricity consumption because it affects new buildings differently from old buildings.[9] This third distinction is most likely a newness effect that could easily be mistaken for the efficacy of building codes.

In the context of wages, Deaton (1985), Foster (1990), and Borjas (2013) have all discussed the difficulties of simultaneously controlling for age, cohort, and year. The most common solution involves using economic theory to assume that one of those three variables is non-linear; for example, using life-cycle theory to suggest that the wage–age profile is concave. Similarly Borjas (1995) assumes that the year effects are the same for immigrants and native workers. I could do something similar, by assuming a concave functional form for the effect of building age and assuming that the general year effects apply to all buildings equally. But each of those assumptions has different implications for the measured vintage effects, which proxy for the changing building codes at the heart of this paper. I do not want those assumptions or their effects to be hidden.

Instead, I control for general time effects with year-of-survey dummies and for vintage of construction with vintage dummies, but I do not control for building age. That means that the vintage dummies, which report residential energy consumption for homes constructed at different times controlling for other characteristics, combine the vintage and age effects. In this way I bias the results in favor of finding that more newly constructed homes (which are also newer) use less energy. But because the newness effect fades over time, that bias will be strongest in the most recent years and will stand out in the patterns of vintage coefficients.

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[9] The slopes of the energy-age profiles are statistically indistinguishable for all but the newest buildings.

A building's vintage also matters when accounting for a second overlooked issue: the rising and falling trend in electrification of heat and hot water. If ignored, it could seem as though homes built since California's 1978 building codes use less electricity because of those codes, rather than because of nationwide trends in home construction.

Electrification of Heat and Hot Water

Figure 4 plots the proportion of homes with electric space heat or hot water in California, according to when the homes were built. Electrification increased until the late 1970s, when 15 percent of homes had electric heat, hot water, or both. After that, the trend reversed, so that very few homes built recently have electric hot water and almost none have electric heat. Why? In the 1950s a consortium of utilities and appliance manufacturers launched "Live Better Electrically" campaigns, granting allowances to home builders to construct all-electric homes throughout the United States.[10] But by the 1980s, the program had ended along with popularity of all-electric homes.

The pattern depicted in Figure 4 has huge implications for electricity use by building vintage. In what follows, I account for the pattern in several ways. In most cases I focus on electricity and limit the sample to single-family homes without electric heat or hot water. In alternative specifications (not reported here) where I do include homes with electric heat and hot water, I include indicator variables for electric heat and hot water along with interactions between those indicators and home size and the number of occupants. The results are identical. And finally, when I examine total energy use I add together consumption of electricity, natural gas, and fuel oil, all measured in millions of British thermal units (MBTUs).

All of this will be clearer with some results in hand, and so with those preliminary caveats out of the way, in the next three sections I discuss each of the three empirical approaches to assessing the energy savings from California's building energy codes.

Strategy 1: Controlling for House and Homeowner Characteristics

The first approach is straightforward. I regress annual household energy use on occupant characteristics, building characteristics, a dummy for the survey year, and a set of indicators for each of the different construction vintages. If building codes have been effective, we should expect homes constructed after California's 1978 standards to be using less energy today than homes built before the codes were enacted, controlling for other observable features of the houses and their occupants.

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[10] Not-yet-Governor Ronald Reagan promoted the program on his show "General Electric Theater." See "The All-Consuming Bills of an All-Electric Home" *Los Angeles Times*, August 13, 2001.

I start with electricity because patterns of electricity use are often cited as evidence for the success of California's energy-efficiency standards (Rosenfeld and Poskanzer, 2009) and because electricity generation has become a focus of energy and environmental policy now that greenhouse gas emissions have become a central concern. The basic specification is as follows:

$$BTU_i = \sum_j \alpha_j HouseFeature_j + \sum_j \beta_j OccupantCharacteristic_j + \sum_j \gamma_j Appliances_j + \sum_j \delta_j SurveyYear_j + \sum_{j=1}^{12} \theta_j ConstructEra_j + \varepsilon_i \quad \textbf{(1)}$$

Table 3 presents the results using the RASS survey.[11] Column (1) includes as covariates only the construction-era dummies and a dummy for the 2009 RASS. The construction-era coefficients steadily increase because on average newly constructed homes use more electricity. Column (2) adds building and occupant characteristics, including size, whether the building was remodeled, the number of residents, their ages, educations, and incomes, and 13 climate-zone fixed effects. And column (3) adds indicators for whether the home has air conditioning and the number of refrigerators and freezers in the house.[12]

To help understand the pattern of coefficients on the construction-era dummies, I have plotted them in Figure 5. The figure contains two sets of bars. The first unshaded set is from column (1) of Table 3, the regression that includes no building or occupant characteristics. The second shaded set of bars is from column (3), with the full set of controls. The vertical line in in Figure 5 is drawn to highlight 1980, after which California's new energy building codes began requiring new homes to meet efficiency standards. In general, new homes do not appear to consume less electricity than homes built prior to California’s building codes. The only one of the 12 construction-era coefficients in column (3) that is statistically lower than the others is the last one, for homes built after 2005. And those homes are new, appearing only in the one 2009 cross section.

In column (4) of Table 3 I estimate a version of equation (1) in which the dependent variable is the log of annual household electricity use. The construction era coefficients can then be interpreted as percentage differences relative to homes built prior to 1940. They range between 0.94 and 0.157, only dropping significantly for the last category of homes that were built after 2005 and appear only in the 2009 cross section.

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[11] For brevity, Table 3 only reports the construction era coefficients. Complete results are in the appendix.

[12] One could argue that air conditioning should be excluded from the control variables. While newer houses are more likely to have air conditioning, that may be a response to the energy efficiency codes rather than something to be controlled for. Part of the rebound effect may be that homeowners or home builders add air conditioning, knowing that the cost of running those systems will be lower. To be thorough, I have included both versions.

For comparison the last column of Table 3 contains a version of equation (1) where the dependent variable is natural gas, rather than electricity. The construction era coefficients display a steady downward trend. Homes built in the late 1970s, before California's building codes took effect, were already using 8 MBTUs less natural gas per year than homes built before 1940. Homes built most recently use another 8 MBTUs less than those built in the late 1970s. Newer homes do appear to use less natural gas than older homes, even after adjusting for home and occupant characteristics. But that pattern is apparent for homes built both before and after the establishment of California's building codes, and appears to have been unchanged by those codes.

Table 4 repeats the exercise for electricity using the RECS data. The RECS has more cross sections but fewer observations for just California. Climate zones within California are not identified, but local heating and cooling degree days are.[13] The RECS has fewer construction-era categories, only identifying the decade of construction. But the pattern is the same. With no controls, in column (1), newly constructed buildings use more electricity. With full controls, in column (3), there is no statistically significant difference between the electricity consumption of homes constructed during different decades. Figure 6 plots those construction-era coefficients.

Why would houses built under tighter building codes not use less electricity? Newer houses may have more electricity-using features, including more televisions, cable boxes, and garage door openers, not all of which I can account for, and that might explain part of the trend. And if newer houses are also better insulated, thanks in part to building codes, their occupants might choose to be less frugal with electricity consumption, offsetting energy savings from that insulation.[14]

One possible explanation for the fact that California homes built since 1978 use no less electricity than homes constructed before the building codes might be that the older homes have been upgraded. Look back at Table 1. Chances are, homes built in the 1960s no longer have their original cooling or heating systems, water heaters, or lighting. They may have replaced the windows, or even added insulation.[15] If that's the case, then the analysis so far doesn't tell us that the estimated energy consumption by new buildings was wrong, but rather that the estimated "business-as-usual" energy consumption by old buildings was wrong. Either way, houses built under stricter building codes do not use significantly less electricity, even after adjusting for the characteristics of the house and its occupants. And whatever the reason, building codes should not be credited with an 80 percent reduction in energy use in perpetuity if the older buildings eventually consume similar amounts of energy.

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[13] A degree day is the difference between the average of the daily maximum and minimum temperatures and 65°F. A heating degree day occurs when that average temperature is less than 65°, and a cooling degree when it is greater than 65°.
[14] Note that the explanation is not that newer houses are more likely to have electric heaters or hot water, as the sample excludes homes with electric space or water heating.
[15] The RASS survey does have an indicator for whether a home has been "remodeled", but its coefficient in Table 3 is positive. Remodeled homes may improve energy efficiency, but on balance they use more energy than otherwise similar homes that have not been remodeled.

But the analysis so far leaves out one important problem—selection by tenants into energy-efficient homes. If people who really like air conditioning buy or rent energy-efficient newer homes, while people who prefer open windows choose less efficient older homes, that might explain the lack of observed difference in energy use. New buildings do save energy, but their occupants differ from those of older homes in ways I have missed.

The next two strategies I employ attempt to address that selection problem. The idea is to look at energy consumption by home vintage, as in Strategy 1, but to differentiate the effect along a dimension that is unlikely to be associated with tenant preferences for energy. I have two in mind: unexpectedly hot temperatures, and comparisons between California and other states.

Strategy 2: Temperature Effects

Most of the building code stipulations described in Table 1 involve weatherization. Half the $8,000 cost the regulations imposed on detached Sacramento homes were for insulation and window glazing, and one-sixth were for other building-envelope and space cooling or heating features. To test whether these insulation components of California's codes have been effective, I turn to an examination of how energy use responds to hot weather. If the codes work as planned, energy use should increase less on hot days for building constructed under more stringent standards. And if those temperature increases are unexpected or unusual for a region, that may mitigate the selection problem.

This approach is based on Chong (2012), who matches tax assessment data with utility billing records in Riverside, California. He finds that homes use more energy during hot months and that homes built since the 1978 building codes have an even larger hot-weather energy increase. Chong controls for home size in square feet, but because he uses tax assessment data, he has no other information about the homes' characteristics or the residents' demographics. New homes have more occupants with higher incomes, and that could in theory explain his finding.

To replicate Chong but with a full set of home and occupant characteristics, I turn to the monthly billing data in the RASS.[16] I match the monthly electricity use with the number of cooling degree days for nearby weather stations each month.

To match the RASS homes to the NOAA weather data, I match the zip codes of the RASS homes to the latitudes and longitudes of the NOAA weather stations. For each zip code, I get the latitude and longitude of the population-weighted centroid from the Census Bureau. I then draw a 20-kilometer circle around that centroid and calculate a weighted average of the reported weather

[16] Billing dates do not correspond exactly to months: the billing date is not typically the last or first day of the month, and days of usage are often more or less than a full month. So to match the temperature data I "calendarized" the billing data by assigning usage proportionally to the months spanned by each utility bill. The 2003 RASS data I received from the California Energy Commission had already been calendarized this way; I replicated that exercise for 2009.

variables for all the NOAA weather stations inside that circle and where the weights are the inverse of the distance from the weather station to the zip code centroid.

Figure 7 plots fitted values of electricity use regressed on a quadratic function of cooling degree days (*CDD*), house fixed effects (γ_i), and month fixed effects (γ_m).

$$BTU_{im} = \alpha_1 CDD_{im} + \alpha_2 (CDD_{im})^2 + \gamma_i + \gamma_m + \varepsilon_i \quad \textbf{(2)}$$

I ran the regression in equation (2) twice: once for homes constructed before 1980 and once for homes constructed after 1980. The homes built after 1980 use more electricity, as noted by the previous section. But the question here is whether the *slope* of the electricity–temperature line is steeper before or after 1980. The fact that the post-1980 line in Figure 7 is higher than the pre-1980 line might have to do with the number and types of appliances in homes or the selection by energy-demanding residents into newer, more energy-efficient houses. But the slopes of those lines involve the sensitivity of energy use to extremes of temperature, something the building codes are intended to moderate.

To examine whether those slopes differ by building vintage, I estimate versions of

$$BTU_{im} = \alpha_1 CDD_{im} + \sum_{j=1}^{12} \theta_j ConstructEra_j + \sum_{j=1}^{12} \pi_j (CDD_{im})(ConstructEra_j) + \boldsymbol{\beta X_i} + \boldsymbol{\gamma_m} + \varepsilon_{im} \quad \textbf{(3)}$$

The coefficients π on the interaction between cooling degree days (*CDD*) and construction era dummies estimate whether during hot months, homes built during period *j* use more electricity.

Table 5 estimates versions of equation (3). The first column excludes the home and occupant characteristics, ***X***, in equation (3). The coefficients π rise steadily. Not only do more recently built homes use more electricity than homes built before the building codes but electricity use in newer homes rises faster when the temperature increases. Column (2) adds the full set of home characteristics, including separate fixed effects for each county–month combination. If anything, the interaction coefficients grow. New homes appear even more sensitive to monthly weather increases once we control for observable house and occupant characteristics. Other specifications (not reported) include zip code–month fixed effects and house fixed effects, with similar results. The results are consistent with Chong (2012) but are puzzling.

Why might electricity use increase with temperature more in newer homes than older ones, controlling for other house and occupant characteristics? One possible omitted variable is tree shade. If older homes are surrounded by taller trees that reduce air conditioning demand on hot days by providing shade, that might explain why electricity use in older homes increases less on hot days. Maher (2013) estimates that homes in Florida that have had nearby trees removed use 3 percent more electricity the following year.

But another explanation could be that column (2) of Table 5 doesn't really solve the selection problem. The interaction terms are identified by temperatures that differ from the norm in that county in that month. In other words, if August is typically a hot month in Sacramento, that effect is absorbed by the county–month fixed effect. But if August 2009 is particularly hot in one zip code within Sacramento, that effect is identified by the cooling degree day coefficient and its interactions with the construction-era dummies. However, if energy-demanding residents are especially keen to buy energy-efficient homes in zip codes where the summer temperatures rise the highest, or have the potential to rise the highest, that may explain why newer homes use more when the temperature is hotter than the norm for the county.

To address this, I construct an alternative temperature measure: the difference between the current monthly cooling degree days in a zip code and the 10-year average cooling degree days for that month in that zip code. This difference is effectively a temperature "surprise": People might know that a particular zip code is in a hot part of Sacramento, or that August temperatures are particularly hot in that zip code. This difference variable is the cooling degree days in that zip code in excess of the average monthly levels.

Column (3) of Table 5 regresses monthly household electricity on the 10-year-average cooling degree days for the zip code, the difference between current monthly cooling degree days and that 10-year average, interactions between that difference and the construction-era dummies, and the rest of the house and occupant characteristics. Now the interaction coefficients are essentially flat. New homes do not use more electricity than older homes during unexpectedly hot weather.

Figure 8 plots the interaction coefficients from columns (1) and (3) of Table 5. The height of the bars can be thought of as the weather sensitivity of electricity use for homes built in different eras (the slopes of the electricity/cooling degree day lines for each vintage). When the weather gets hot, electricity use increases *more* in homes built after 1980 than in homes built before 1980, but that outcome disappears for temperature surprises, controlling for other house and occupant characteristics. By controlling for other home characteristics and expected monthly differences in weather, it seems possible to show that electricity use in newer houses does not increase *more* during hot weather. But if energy building codes mean that newer homes use less energy, we should have expected electricity to increase *less*.

Strategy 3: Comparing California to Other States

Proponents of energy-efficiency standards have for a long time pointed to the sharp differences between electricity consumption per capita in California and other states as evidence of the effectiveness of California's policies. Since 1978, when the California Energy Commission began setting energy-efficiency building codes, electricity use per capita has remained roughly flat in California while growing by 75 percent in the rest of the United States (Rosenfeld and Poskanzer, 2009). In Levinson (2014) I show that most of that gap can be explained by trends unrelated to building codes: the shifting of the rest of the United States population toward hotter regions; California's mild climate; and falling household sizes in other states. But that doesn't mean the building codes have not been effective, only that their effectiveness cannot be assessed by comparing electricity consumption trends in California and other states.

Instead of comparing electricity consumption in California and other states directly, in this section I compare the relationship between electricity consumption and building vintage in California and other states. If California's building codes reduce energy use, buildings constructed under newer, more stringent codes should use less energy than buildings constructed in the past. The previous two strategies failed to find such a distinction, but perhaps that is because some omitted variable is correlated with both building vintage and energy use. When I do not control for any building or occupant characteristics, the vintage-electricity profile is steep; once I control for characteristics, the profile is nearly flat. Perhaps there are omitted characteristics that if included would reverse the profile so that recent vintages use less electricity. If those omitted variables work similarly in California and other states, then the difference between the vintage-electricity profiles in California and other states will reveal the efficacy of the building codes.

To compare vintage and electricity use in California and other states, I turn to the RECS. The basic approach can be seen in Figure 9. The lightly shaded bars plot the average annual energy consumption for households of different vintages in the other 49 states, without controlling for other characteristics. The darkly shaded bars plots those same calculations for households in California. Californians use less electricity per household, and both lines exhibit the same pattern where newer homes use more energy. The question posed here is whether, controlling for other household characteristics, the difference between California and other states' electricity is larger for newer vintages after California enacted its strict building codes.

Table 6 addresses that question. Column (2) regresses electricity use on an indicator for California homes, building and occupant characteristics, and interactions between building vintage and the California indicator. The interactions between the California indicator and building vintages are plotted in Figure 10. They do not suggest that the gap between California and other states is larger after 1980. The coefficient on the 1980s interaction (-4.41) is negative and statistically significant, meaning that the difference between homes built in the 1980s and those built before 1940 (the omitted category) is 4.4 MBTU smaller in California. But that difference is the same size as for homes built in the 1970s, before the codes were enacted, and the difference grows and is statistically insignificant for homes built in the 1990s and 2000s. Whatever makes electricity use lower in California than other states does so for buildings of all vintages and did not become larger for homes built to meet California's post-1970s building codes.

Column (3) of Table 6 expands the analysis to include fuel oil and natural gas, energy sources that are more prevalent outside of California. Many of the interaction coefficients are positive, meaning that total energy use is lower in homes built before 1940 (the omitted category). But for homes built after 1940, the same pattern appears for all energy as for electricity. There is no statistically significant distinction between energy use by homes built before and after California enacted its building standards.

Frequently Asked Questions

Control for Air Conditioning?

Homes constructed more recently are more likely to have air conditioning. That accounts for some, but not all, of the fact that those homes use more electricity. Should that be a control variable when estimating the efficacy of building standards? Air conditioning installation is a choice of the builder and homeowner, not something that is regulated by the building codes. Energy efficiency makes air conditioning less expensive and may influence both the decision to install it and how much to use it. If more buildings have air conditioning because the building codes have made it less expensive, that is a reason not to control for it. Given that the bottom line finding of this project is that homes constructed since California instituted its building energy codes do not use less energy than homes built before the energy codes, I have taken the conservative approach of including controls for air conditioning.[17]

Control for Remodels and Retrofits?

One reason that homes of older vintages may not use more energy, other things equal, is that they may have been remodeled or retrofitted with new windows, added insulation, or upgraded heating and cooling systems. The codes might have saved future homeowners the effort and expense of those remodels. But that would mean the energy-saving benefits of building codes should not be credited with those savings in perpetuity, only until such time as the old buildings catch up with the new.

If remodels and retrofits explain this result, that means the business-as-usual projected energy use was wrong. Engineers may have correctly predicted energy use by newly regulated construction but overstated the energy use by homes built absent the standards. If those unregulated homes would eventually be more energy efficient anyway, then the savings from the building standards are smaller and shorter-lived than predicted.

In the first strategy taken, where I simply regress electricity use on home characteristics, I do control for a rough indicator of whether or not the home has been remodeled. This can include anything from bathroom renovations to major home additions. The coefficient on that indicator is positive, suggesting that when people remodel homes, they may upgrade the energy efficiency but also add energy-using features.

Selective Destruction?

[17] In other specifications (not reported), I have interacted air conditioning with home size, with no appreciable effect on the results.

One reason I may fail to find that buildings constructed after California's energy codes use less energy than those constructed before involves the selective destruction of older buildings. Perhaps the worst-constructed, energy-inefficient older homes are most likely to be demolished, leaving only the most energy efficient older homes in the current data. If so, the sample of buildings constructed after the building codes includes both good and bad construction, while the sample constructed before the codes includes only the best buildings. In that case this exercise may appear to be stacked against finding an energy-saving benefit of the building codes. But if that pattern of demolition represents the business-as-usual lifetimes of buildings, those poorly-built older buildings were not destined to last long anyway. They do not belong in the business-as-usual base case for calculating the long-run energy savings from building codes.

Conclusion

Building codes regulate home characteristics for which buyers have an information disadvantage, including fire safety, construction, and energy efficiency. Buyers cannot easily assess whether the electric wiring or stairways are safe, the roof appropriate for local weather, or the insulation sufficient to keep the house comfortable. Building standards may help prevent the occasional unscrupulous homebuilder from cutting corners on those hidden costs. That goal—addressing the asymmetric information market failure—provides justification for building codes of all types, including energy-efficiency standards. The point of this paper is to assess the claim that building energy-efficiency standards save energy. Although they do not seem to, that is not a reason by itself to condemn the standards, just a reason not to rely on those standards to reduce pollution or slow climate change.

California's energy-efficient building codes were advertised as reducing energy consumption for new buildings by 80 percent. All I have done here is to document that homes constructed since California instituted its building energy codes are not using less electricity today than homes built before the codes came into effect, controlling for observable characteristics of those houses and their occupants. The analysis does not explain why such a large gap remains between the promise and the reality, but I can speculate.

The engineering models that predict large gains may be wrong, failing to account for human nature, owners' failure to maintain insulation or appliances, or the rebound effect. Compliance with building codes may be less than perfect. Or the owners of older homes may have retrofitted those homes to be more energy efficient. If any of these explanations accounts for the result, the building codes may well have served their purpose of protecting homeowners from corner-cutting builders, saving homeowners money, or making them more comfortable. But the codes will not have reduced energy use or carbon pollution relative to business-as-usual trends.

On the other hand, the predictions may be correct, and these results wrong. I may have failed to account for some home or occupant characteristics that increase energy consumption in new homes relative to old homes, increase electricity use on hot days faster in new homes than old homes, and increase electricity consumption in new homes in California more than new homes in other states. If those explanations account for the result, then building codes may be saving energy and reducing pollution as promised, but those reductions savings are tremendously difficult to measure empirically.

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Table 1. Projected Savings and Costs from 1980 California Energy Codes: Single-Family Homes, Sacramento

	Business as usual	Regulation	Difference
	(1)	(2)	(3)
Insulation	-	$2,831	$2,831
Window glazing	$879	2,108	1,229
Overhang	-	468	468
Shading	-	360	360
Caulking, sealing, etc.	-	551	551
Thermostat	82	138	56
Heating system	1,360	1,360	-
Cooling system	1,129	965	−164
Duct insulation	-	61	61
Total building envelope	**$3,450**	**$8,842**	**$5,392**
Water heater	284	2,736	2,452
Lighting	97	333	236
Total initial cost	**$3,831**	**$11,911**	**$8,080**
Total energy (1,000 BTU)	**187,209**	**43,025**	**144,184**
Energy savings			**77%**

Note: The median California home price in 1980 was $80,000.
Source: Horn et al., 1980.

Table 2. Electricity Use by California Homes Built 1998–2000 and 2001–2004

		Electricity ln(MBTU)		All energy ln(MBTU)	
	Averages	2003	2009	2003	2009
		(1)	(2)	(3)	(4)
Built 2001–2004	**0.46**	**-0.12***	**0.00**	**-0.13***	**-0.02**
		(0.06)	**(0.05)**	**(0.06)**	**(0.04)**
ln(square feet)	0.82	0.63*	0.47*	0.40*	0.48*
	(0.01)	(0.10)	(0.09)	(0.09)	(0.08)
ln(bedrooms)	1.27	0.06	0.15	0.22	0.12
	(0.01)	(0.14)	(0.12)	(0.13)	(0.11)
Air conditioning	0.82	0.19*	0.09	0.22*	0.07
		(0.09)	(0.08)	(0.08)	(0.07)
Constant		2.03*	1.82*	2.73*	2.61*
		(0.45)	(0.48)	(0.43)	(0.39)
Zip code fixed effects		yes	yes	yes	yes
Observations	1,311	548	846	574	731
R-squared		0.733	0.603	0.792	0.594

Standard errors in parentheses. (Standard deviations in first column.)
* $p<0.05$
Source: Residential Appliance Saturation Study 2003 and 2009.

Table 3. Electricity Use by California Households in the RASS Survey

	Annual household electricity (MBTU)				
	No controls	Building and occupant controls	Appliance controls	In logs	Natural Gas
	(1)	(2)	(3)	(4)	(5)
Building characteristics: ln(square feet), bedrooms, electric stove, electric oven, remodeled	no	yes	yes	yes	yes
Occupant characteristics: ln(years at address), ln(number of residents), ln(household income), residents aged 0–5, residents aged 65–99, household head graduated college, disabled resident, household head Black, household head Latino, own home	no	yes	yes	yes	yes
Appliances: central AC, room AC, refrigerators, freezers	no	no	yes	yes	yes
Year 2009 RASS	3.27*	2.61*	1.98*	0.137*	0.08
	(0.24)	(0.21)	(0.20)	(0.011)	(0.50)
Built 1940s	1.06*	1.02*	0.54	0.094*	-2.29*
	(0.52)	(0.46)	(0.45)	(0.028)	(1.08)
Built 1950s	3.08*	1.27*	0.59	0.089*	-2.12*
	(0.45)	(0.44)	(0.42)	(0.024)	(1.03)
Built 1960s	5.57*	1.41*	0.44	0.122*	-5.04*
	(0.45)	(0.45)	(0.43)	(0.024)	(1.05)
Built 1970–1974	6.62*	1.76*	0.69	0.119*	-6.51*
	(0.56)	(0.53)	(0.52)	(0.027)	(1.87)
Built 1975–1977	8.53*	2.43*	0.75	0.157*	-7.68*
	(0.64)	(0.59)	(0.57)	(0.027)	(1.34)
Built 1978–1982	8.60*	1.92*	0.32	0.120*	-9.79*
	(0.57)	(0.54)	(0.52)	(0.027)	(1.25)
Built 1983–1992	10.31*	2.45*	0.56	0.115*	-12.33*
	(0.53)	(0.49)	(0.48)	(0.025)	(1.17)
Built 1993–97	10.27*	1.63*	-0.25	0.113*	-16.27*
	(0.71)	(0.64)	(0.63)	(0.028)	(1.49)
Built 1998–2000	10.08*	0.94	-0.75	0.100*	-16.20*
	(0.75)	(0.71)	(0.68)	(0.030)	(1.53)
Built 2001–2004	11.14*	0.26	-1.34	0.085*	-17.45*
	(0.76)	(0.73)	(0.71)	(0.030)	(1.49)
Built 2005–2008	10.25*	-1.82	-3.90*	-0.037	-16.11*
	(1.02)	(0.99)	(0.98)	(0.041)	(2.35)
13 climate zone dummies	no	yes	yes	yes	yes
Observations	16,301	16,301	16,301	16,301	15,907
R-squared	0.052	0.298	0.360	0.300	0.147

Heteroskedastic-consistent standard errors in parentheses. Includes year of survey dummy for 2009.
* p<0.05
Full set of coefficients in Appendix.
Source: Residential Appliance Saturation Study (RASS) 2003 and 2009.

Table 4. Electricity Use by California Households in the RECS Survey

Dependent variable: Annual household electricity (MBTU)	No Controls (1)	Building and occupant controls (2)	Appliance controls (3)
ln(square feet)		4.828*	4.049*
		(0.922)	(0.945)
Rooms		2.170*	1.852*
		(0.316)	(0.289)
ln(number of residents)		5.459*	5.245*
		(0.729)	(0.698)
ln(household income)		2.424*	1.936*
		(0.398)	(0.399)
Kids		-0.805*	-0.757*
		(0.380)	(0.369)
Seniors		0.790	0.328
		(0.559)	(0.565)
Owner-occupied		-1.019	-1.527
		(0.875)	(0.845)
Central AC			5.540*
			(0.687)
Refrigerators			4.520*
			(0.890)
Heating degree days			0.182*
			(0.0285)
Cooling degree days			0.466*
			(0.0765)
Built 1940s	0.926	1.588	1.626
	(1.566)	(1.386)	(1.312)
Built 1950s	3.511*	1.762	1.092
	(1.271)	(1.127)	(1.074)
Built 1960s	3.094*	0.773	-0.0359
	(1.339)	(1.180)	(1.128)
Built 1970s	6.929*	1.758	0.745
	(1.458)	(1.324)	(1.282)
Built 1980s	7.744*	0.339	-0.885
	(1.481)	(1.341)	(1.289)
Built 1990s	8.101*	1.324	-0.362
	(1.584)	(1.361)	(1.333)
Built 2000s	15.30*	5.040	2.521
	(3.639)	(3.426)	(3.518)
Constant	18.34*	-37.35*	-32.65*
	(1.307)	(4.597)	(4.537)
RECS year dummies	yes	yes	yes
Observations	1,773	1,773	1,773
R-squared	0.080	0.300	0.342

Heteroskedastic-consistent standard errors in parentheses. Includes year of survey dummy for 2009.
* $p<0.05$
Source: Residential Energy Consumption Survey (RECS) 1993, 1997, 2001, 2005, and 2009, single-family homes without electric heat or hot water in California.

Table 5. Electricity Use and Monthly Cooling Degree Days (CDD) in California

Dependent variable: Monthly household electricity (BTU)	No controls except vintage and temps (1)	Building, occupant, and appliance controls (2)	Difference from average zip code CDD (3)
CDD per month	4.846*	2.750*	
	(0.138)	(0.131)	
Average monthly CDD in zip code			6.006*
			(0.0753)
CDD – avg, monthly CDD			1.032*
			(0.425)
Vintage of construction fixed effects	yes	yes	yes
CDD × built 1940s	0.954*	0.929*	-0.179
	(0.199)	(0.173)	(0.614)
CDD × built 1950s	0.692*	1.058*	0.329
	(0.156)	(0.136)	(0.498)
CDD × built 1960s	0.838*	1.112*	0.906
	(0.157)	(0.138)	(0.504)
CDD × built 1970–1974	1.278*	1.585*	2.164*
	(0.179)	(0.157)	(0.595)
CDD × built 1975–1977	1.133*	1.582*	0.589
	(0.198)	(0.173)	(0.653)
CDD × built 1978–1982	1.753*	2.352*	1.080
	(0.172)	(0.151)	(0.592)
CDD × built 1983–1992	2.189*	2.754*	1.362*
	(0.152)	(0.134)	(0.505)
CDD × built 1993–1997	2.905*	3.549*	2.504*
	(0.181)	(0.159)	(0.637)
CDD × built 1998–2000	2.465*	2.925*	0.596
	(0.192)	(0.169)	(0.670)
CDD × built 2001–2004	2.822*	3.453*	0.645
	(0.185)	(0.163)	(0.647)
CDD × built 2005–2008	1.065*	1.930*	-0.710
	(0.206)	(0.180)	(0.739)
House characteristics: bedrooms, electric stove, oven, remodeled, ln(years at address), ln(residents), ln(household income), residents aged 0–5, residents aged 65–99, household head graduated college, disabled resident, household head Black, household head Latino, own home, central AC, room AC, refrigerators, freezers, RASS 2009	no	yes	yes
12-month fixed effects	yes	no	no
County–month fixed effects	no	yes	yes
Observations	259,007	259,007	259,007
R-squared	0.143	0.363	0.362

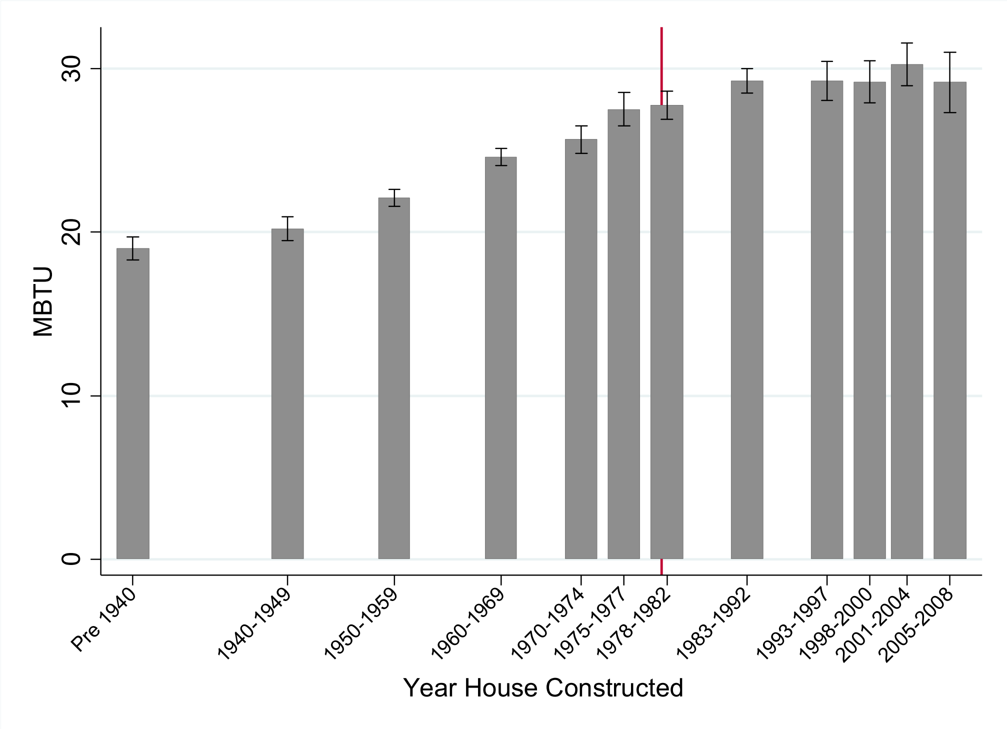
Heteroskedastic-consistent standard errors in parentheses. (Standard deviations in first column.) In column (3), the interaction coefficients ("CDD x built 19xx") correspond to interactions with the difference between monthly CDD and the monthly average CDD.
* p<0.05
Full set of coefficients in Appendix.
Source: Residential Appliance Saturation Study (RASS) 2003 and 2009.

Table 6. Comparing California and Other US States

	Averages	Electricity (MBTU)	Total Energy (MBTU)
	(1)	**(2)**	**(3)**
California	0.104	-15.71*	-22.64*
		(1.402)	(3.097)
ln(square feet), rooms, ln(household size), ln(household income), children ≤12,[a] seniors, own home, central AC, refrigerators		yes	yes
Heating degree days (×100)	43.58	0.003	0.477*
	(22.27)	(0.019)	(0.053)
Cooling degree days (×100)	13.62	0.248*	-0.081
	(9.97)	(0.036)	(0.079)
Constructed 1940s	0.079	0.726	-2.347
		(0.708)	(1.778)
Constructed 1950s	0.160	-0.367	-3.825*
		(0.533)	(1.431)
Constructed 1960s	0.136	1.356*	-9.588*
		(0.607)	(1.480)
Constructed 1970s	0.155	6.345*	-22.10*
		(0.643)	(1.520)
Constructed 1980s	0.136	4.605*	-27.12*
		(0.644)	(1.514)
Constructed 1990s	0.094	1.775*	-25.93*
		(0.678)	(1.576)
Constructed 2000s	0.049	0.593	-27.13*
		(0.818)	(1.843)
Constructed 1940s in CA	0.0072	0.964	11.16*
		(1.673)	(4.223)
Constructed 1950s in CA	0.0160	-0.300	6.328*
		(1.196)	(2.879)
Constructed 1960s in CA	0.0124	-3.115*	6.345*
		(1.268)	(3.057)
Constructed 1970s in CA	0.0114	-4.482*	13.72*
		(1.394)	(3.148)
Constructed 1980s in CA	0.0121	-4.408*	12.06*
		(1.404)	(3.329)
Constructed 1990s in CA	0.0079	-2.294	14.65*
		(1.537)	(3.471)
Constructed 2000s in CA	0.0033	5.019	28.52*
		(4.244)	(8.571)
5 RECS survey year fixed effects		✓	✓
Decade of construction fixed effects		✓	✓
9 census division fixed effects		✓	✓
Observations	20,544	20,544	20,544
R-squared		0.346	0.346

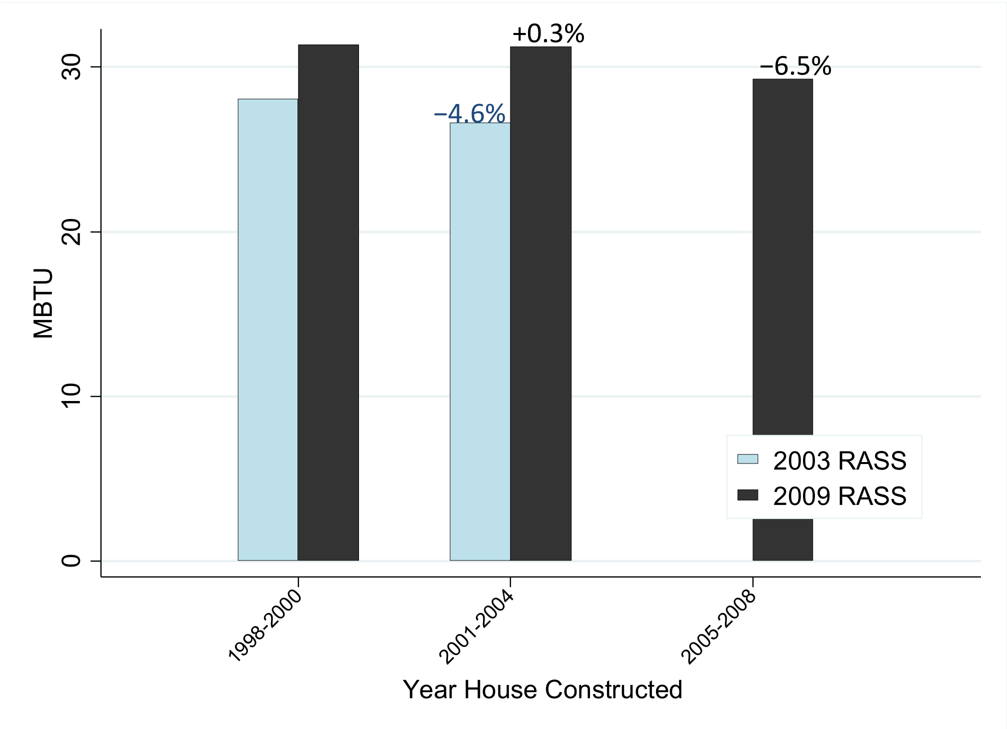
Heteroskedastic-consistent standard errors in parentheses. (Standard deviations in first column.)
Full set of coefficients in Appendix.
Source: Residential Energy Consumption Survey (RECS) 1993–2009.
[a] Children are defined as ≤14 years old in RECS 2009.

Figure 1. Average Annual Household Electricity *Today* in California



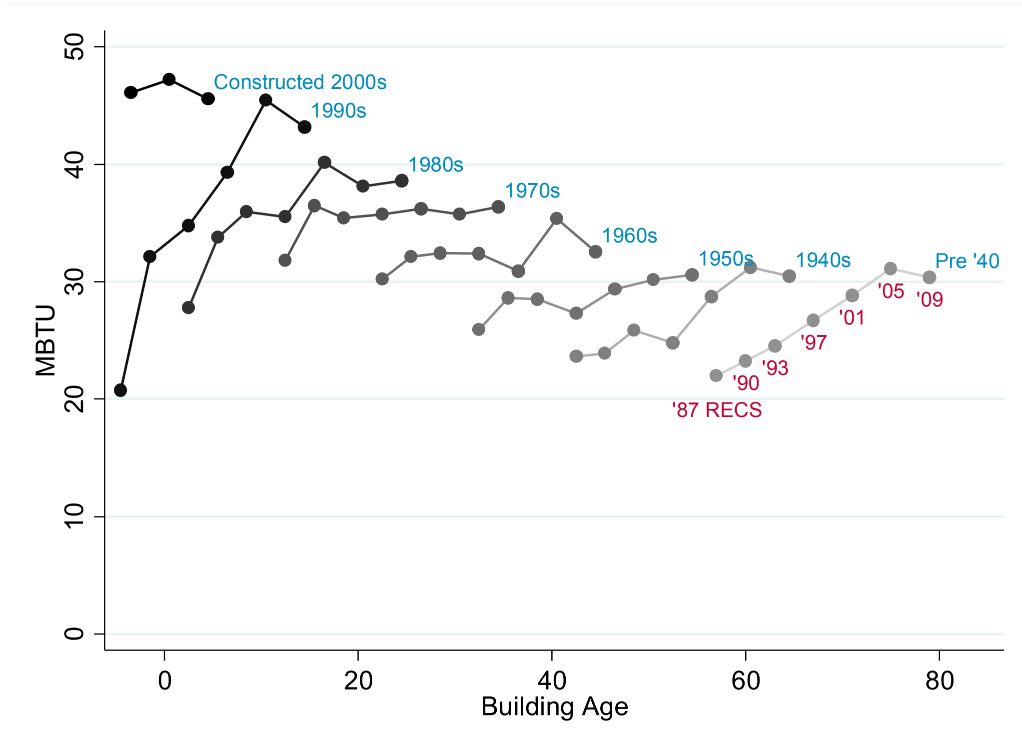
Source: RASS, 2003 and 2009, single-family detached homes without electric heat or hot water.

Figure 2. Household Electricity Use, 2003 and 2009 Surveys



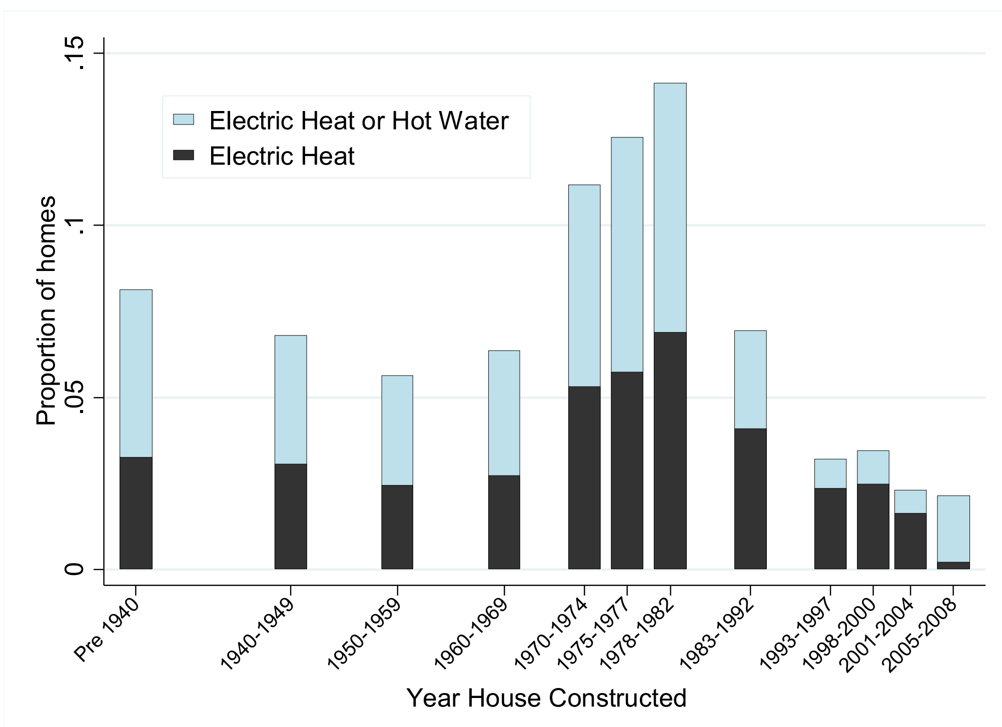
Source: RASS, single-family detached homes without electric heat or hot water.

Figure 3. Household Electricity Use, Synthetic Cohorts by Construction Decade



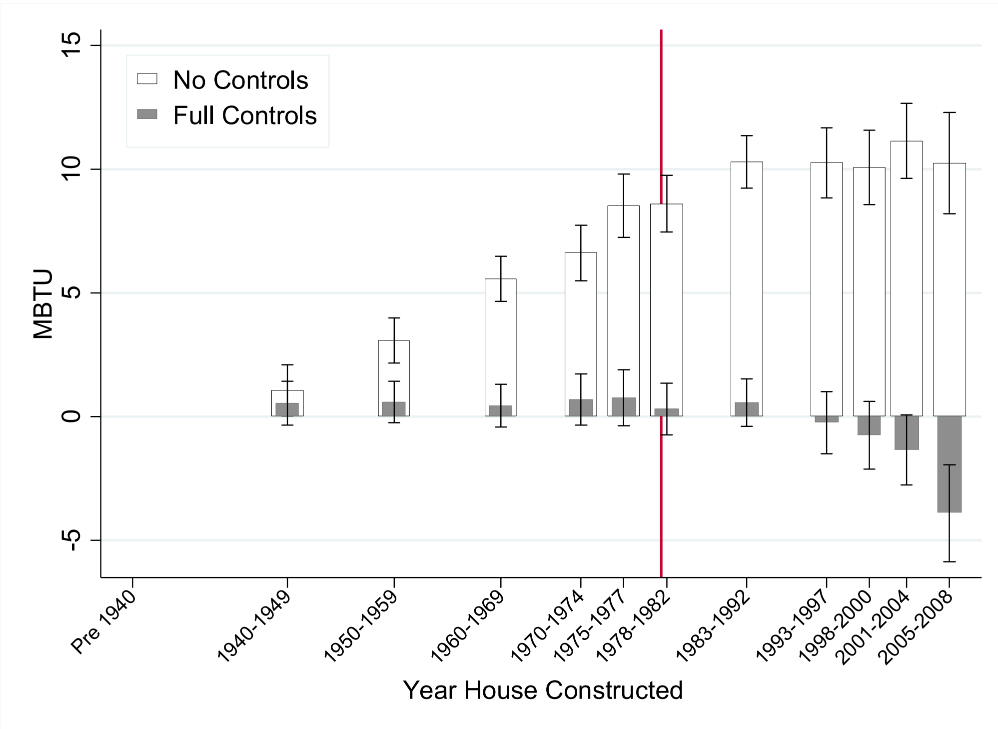
Source: RECS, 1993-2009, single-family detached homes without electric heat or hot water.

Figure 4. Proportion of Homes with Electric Heat, Hot Water



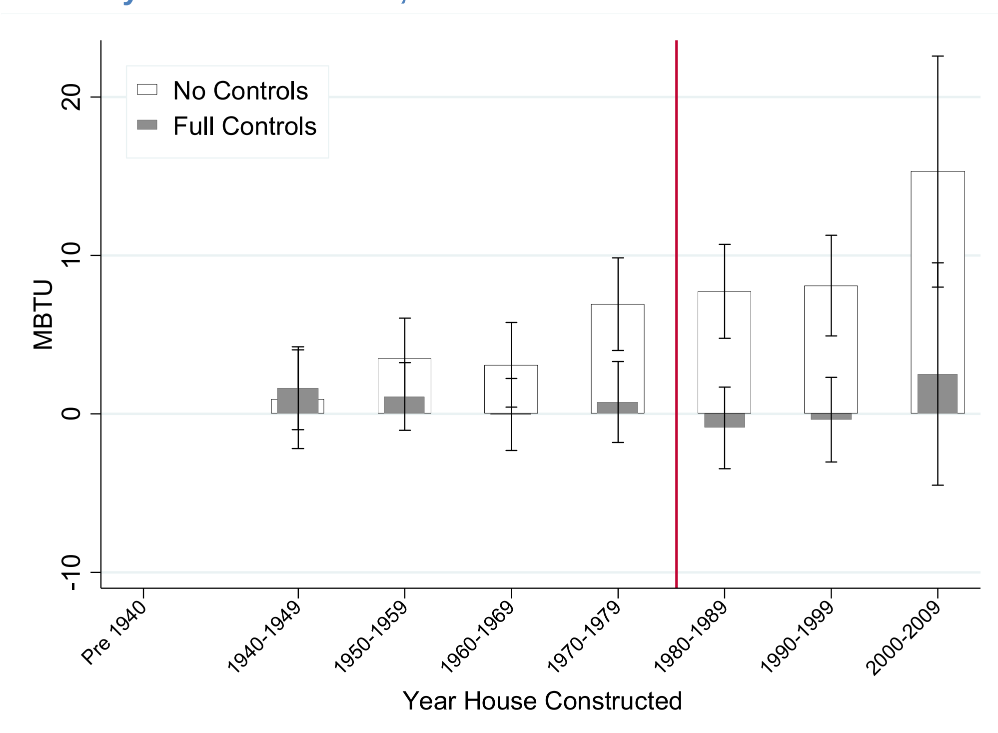
Source: RASS, 2003 and 2009, single-family detached homes.

Figure 5. Electricity Use in the RASS, with and without Covariates



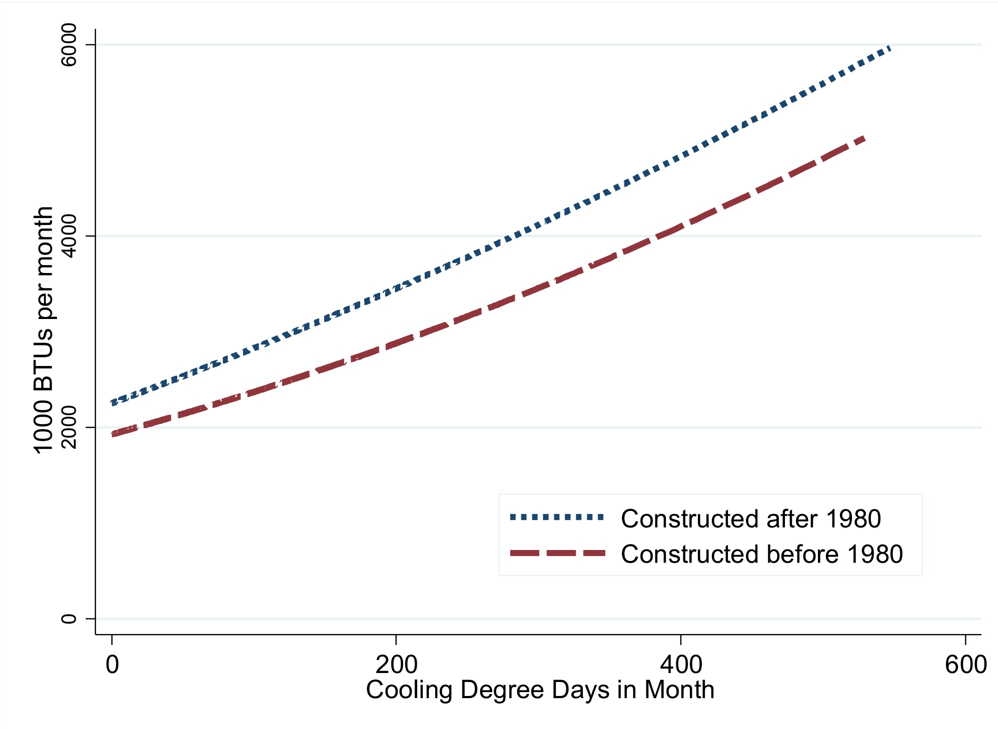
Source: RASS, 2003 and 2009, single-family detached California homes without electric heat or hot water.

Figure 6. Electricity Use in the RECS, With and Without Covariates



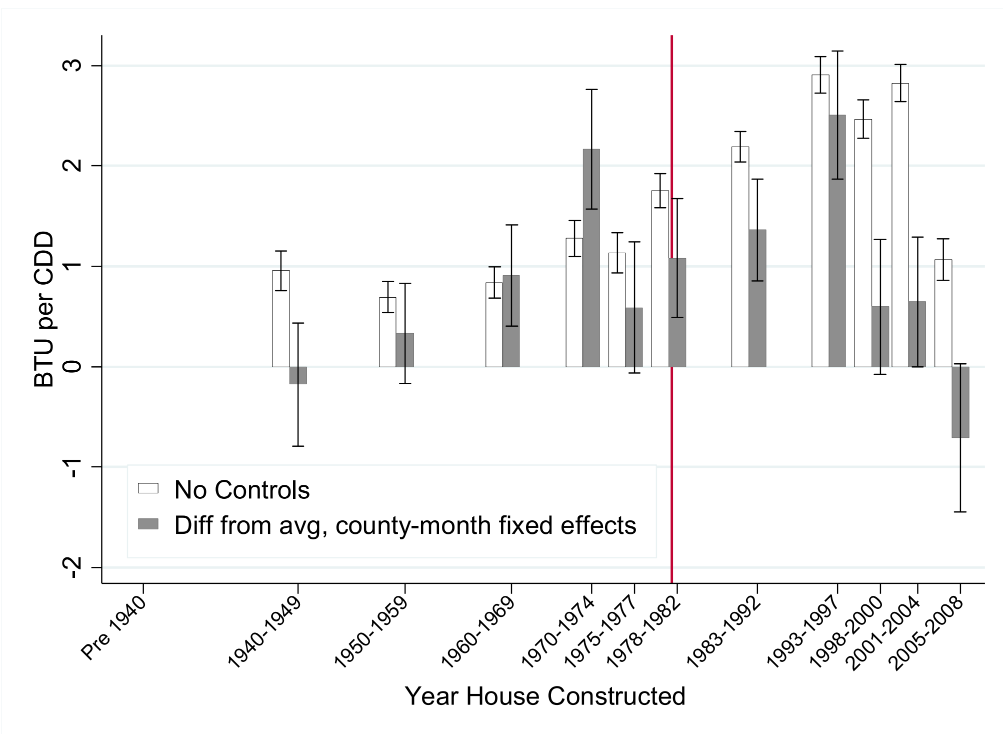
Source: RECS, 1993–2009, single-family detached California homes without electric heat or hot water.

Figure 7. Temperature and Electricity Use



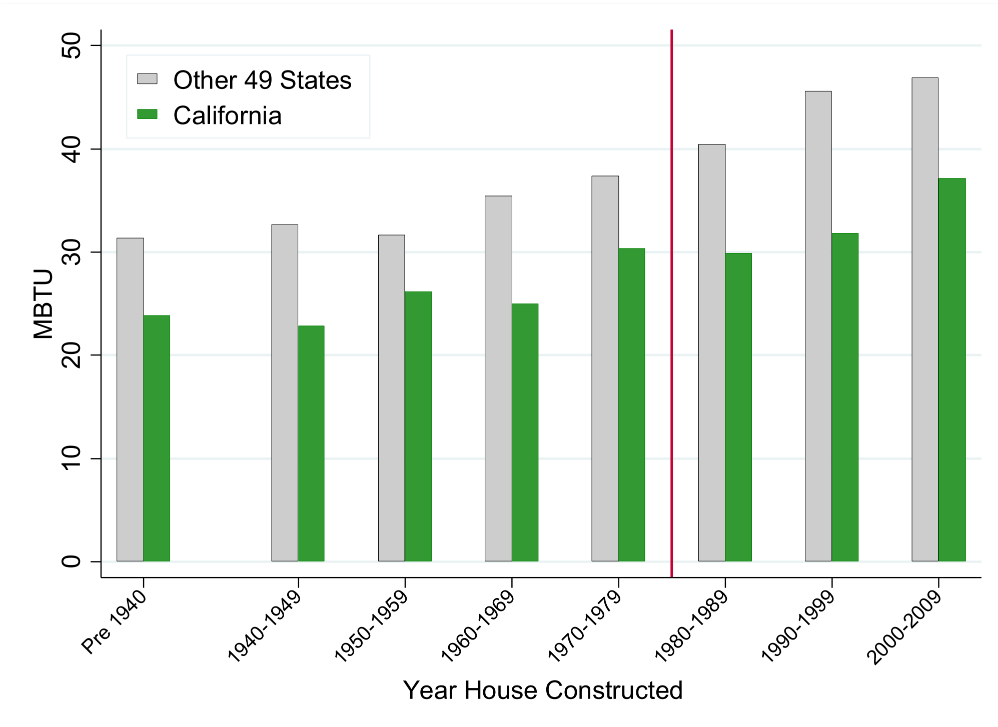
Source: RASSS, 2003 and 2009, single-family detached California homes without electric heat or hot water.

Figure 8. Electricity Use per Cooling Degree Day



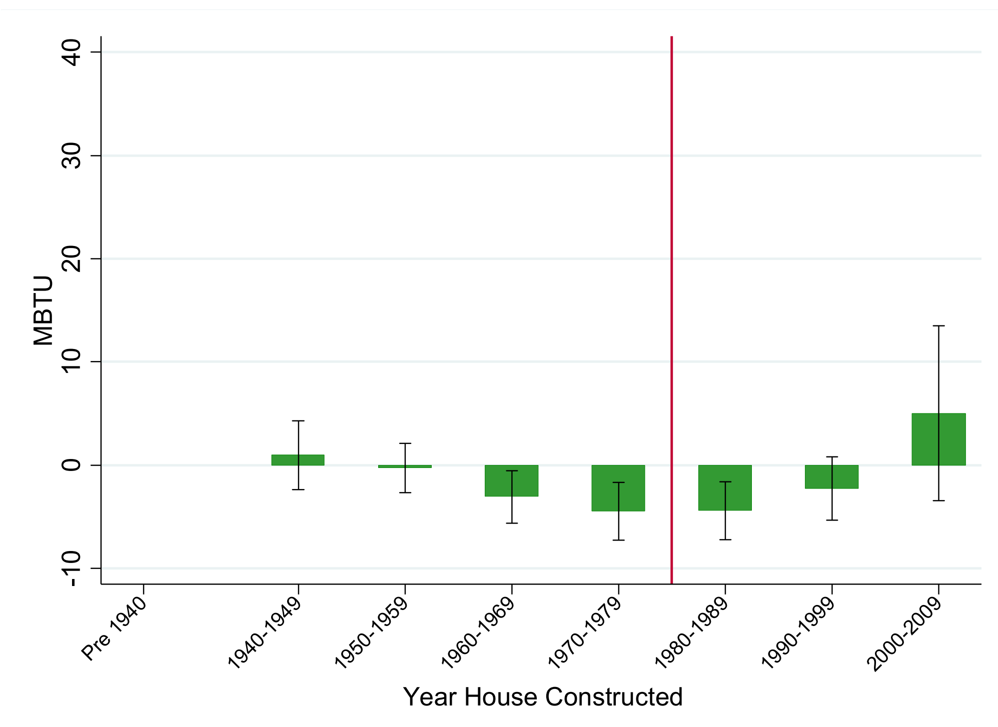
Source: Residential Appliance Saturation Study 2003 and 2009, single-family detached homes.

Figure 9. Electricity Use in the RECS: California and Other States



Source: RECS, 1993–2009, single-family detached homes without electric heat or hot water.

Figure 10. Electricity Use in the RECS: Residual Decade Effects for California



Source: RECS, 1993–2009, single-family detached homes without electric heat or hot water.

APPENDIX TABLES

Table A1.
Means and Standard Deviations in the RASS

Variables	Mean (St. Dev.)
Annual electricity (MBTU)	25.27
	(15.98)
Square feet (1000s)	1.890
	(0.827)
Bedrooms	3.279
	(0.883)
Electric stove	0.274
	(0.446)
Electric oven	0.400
	(0.490)
Remodeled	0.156
	(0.363)
Years at address	11.01
	(6.027)
Number of residents	2.846
	(1.490)
Household income	87.48
	(57.87)
Residents aged 0–5	0.226
	(0.655)
Residents aged 65–99	0.504
	(0.780)
Household head graduated college	0.583
	(0.493)
Disabled resident	0.102
	(0.303)
Household head Black	0.0323
	(0.177)
Household head Latino	0.126
	(0.332)
Own home	0.927
	(0.260)
Central AC	0.525
	(0.499)
Room AC	0.112
	(0.315)
Refrigerators	1.345
	(0.534)
Freezers	0.260
	(0.460)
RASS 2009	0.545
	(0.498)
Observations	16,301

Source: Residential Appliance Saturation Study (RASS) 2003 and 2009, single-family homes without electric heat or hot water.

Table A2.
Means and Standard Deviations in the RECS

Variables	California Mean (St. Dev.)	All states Mean (St. Dev.)
Annual electricity (MBTU)	25.6	32.4
	(15.4)	(19.2)
Natural Gas (MBTU)	53.1	84.1
	(29.2)	(56.8)
Square feet (1000s)	2.22	2.54
	(1.14)	(1.37)
Rooms	6.31	6.61
	(1.64)	(1.78)
Number of residents	3.20	2.94
	(1.69)	(1.51)
Household income (2010 $1,000s)	70.2	64.0
	(40.5)	(38.4)
Kids	0.61	0.59
	(1.02)	(1.00)
Seniors	0.33	0.32
	(0.63)	(0.63)
Own home	0.81	0.87
	(0.39)	
Central AC	0.41	0.50
	(0.49)	
Refrigerators	1.29	1.28
	(0.49)	(0.49)
Heating degree days	19.3	45.4
	(10.0)	(21.6)
Cooling degree days	11.3	12.3
	(6.4)	(8.6)
Observations	1,767	15,933

Source: Residential Energy Consumption Survey 1993–2009, single-family homes without electric heat or hot water.

Table A3.
Electricity Consumption in the RASS

	Annual household electricity (MBTU)				
	No Controls	Building and occupant controls	Appliance controls	In logs	Natural Gas
	(1)	(2)	(3)	(4)	(5)
ln(square feet)		12.04*	9.626*	0.306*	20.54*
		(0.504)	(0.460)	(0.0190)	(1.045)
Bedrooms		0.962*	0.751*	0.0299*	1.725*
		(0.193)	(0.186)	(0.00796)	(0.480)
Electric stove		-1.051*	-0.858*	-0.00701	-2.719*
		(0.340)	(0.323)	(0.0140)	(0.720)
Electric oven		2.293*	2.004*	0.0683*	1.004
		(0.338)	(0.325)	(0.0132)	(0.766)
Remodeled		0.961*	0.726*	0.0475*	-0.558
		(0.302)	(0.288)	(0.0127)	(0.637)
ln(years at address)		0.929*	0.810*	0.0434*	0.711
		(0.152)	(0.146)	(0.00830)	(0.387)
ln(number of residents)		5.702*	5.039*	0.251*	4.491*
		(0.249)	(0.244)	(0.0110)	(0.536)
ln(household income)		2.850*	2.310*	0.0821*	2.852*
		(0.174)	(0.168)	(0.00846)	(0.374)
Residents aged 0–5		-1.016*	-1.007*	-0.0437*	0.777
		(0.187)	(0.181)	(0.00925)	(0.415)
Residents aged 65–99		-0.832*	-1.168*	-0.0389*	2.563*
		(0.150)	(0.143)	(0.00683)	(0.341)
Household head		-2.092*	-1.325*	-0.0530*	-1.150*
graduated college		(0.242)	(0.230)	(0.0108)	(0.460)
Disabled resident		3.987*	3.348*	0.124*	3.053*
		(0.378)	(0.361)	(0.0159)	(0.756)
Household head Black		-0.232	-0.114	0.0176	6.137*
		(0.548)	(0.507)	(0.0301)	(1.185)
Household head Latino		-2.596*	-2.020*	-0.0750*	-0.365
		(0.289)	(0.278)	(0.0150)	(0.931)
Own home		-2.886*	-3.481*	-0.114*	-7.688*
		(0.465)	(0.447)	(0.0200)	(1.646)
Central AC			5.249*	0.241*	1.116*
			(0.238)	(0.0118)	(0.550)
Room AC			1.845*	0.0889*	1.635*
			(0.311)	(0.0168)	(0.721)
Refrigerators			5.724*	0.183*	4.214*
			(0.265)	(0.0102)	(0.563)
Freezers			3.042*	0.130*	-0.388
			(0.255)	(0.0105)	(0.595)
RASS 2009		2.607*	1.980*	0.137*	0.0851
		(0.212)	(0.203)	(0.0111)	(0.501)
Built 1940s	1.060*	1.024*	0.537	0.0941*	-2.287*
	(0.519)	(0.460)	(0.445)	(0.0281)	(1.079)
Built 1950s	3.084*	1.265*	0.585	0.0887*	-2.116*
	(0.453)	(0.435)	(0.419)	(0.0240)	(1.027)
Built 1960s	5.565*	1.405*	0.438	0.122*	-5.038*
	(0.453)	(0.448)	(0.432)	(0.0237)	(1.051)
Built 1970–1974	6.618*	1.761*	0.692	0.119*	-6.513*

	(0.563)	(0.533)	(0.516)	(0.0268)	(1.870)
Built 1975–1977	8.526*	2.429*	0.753	0.157*	-7.675*
	(0.638)	(0.590)	(0.567)	(0.0273)	(1.342)
Built 1978–1982	8.604*	1.915*	0.315	0.120*	-9.792*
	(0.572)	(0.541)	(0.524)	(0.0271)	(1.249)
Built 1983–1992	10.31*	2.450*	0.562	0.115*	-12.33*
	(0.528)	(0.486)	(0.476)	(0.0246)	(1.166)
Built 1993–1997	10.27*	1.631*	-0.248	0.113*	-16.27*
	(0.710)	(0.641)	(0.630)	(0.0277)	(1.490)
Built 1998–2000	10.08*	0.944	-0.751	0.0999*	-16.20*
	(0.754)	(0.706)	(0.683)	(0.0301)	(1.532)
Built 2001–2004	11.14*	0.255	-1.344	0.0848*	-17.45*
	(0.760)	(0.734)	(0.707)	(0.0300)	(1.490)
Built 2005–2008	10.25*	-1.817	-3.904*	-0.0365	-16.11*
	(1.018)	(0.990)	(0.981)	(0.0407)	(2.349)
Constant	19.08*	-3.801*	-8.040*	1.575*	9.878*
	(0.363)	(1.013)	(1.006)	(0.0523)	(3.040)
13 climate zone dummies	no	yes	yes	yes	yes
Observations	16,301	16,301	16,301	16,301	15,907
R-squared	0.052	0.298	0.360	0.300	0.147

Heteroskedastic-consistent standard errors in parentheses. (Standard deviations in first column.)
Source: Residential Appliance Saturation Study (RASS) 2003 and 2009.

Table A4.
Monthly Electricity Consumption and Temperatures in California

Dependent variable: Monthly household electricity (BTU)	No Controls except vintage and temps (1)	Building, occupant, and appliances (2)	Difference from average zip code cooling degree day (CDD) (3)
CDD per month	4.846*	2.750*	
	(0.138)	(0.131)	
Average monthly CDD in zip code			6.006*
			(0.0753)
CDD – avg, monthly CDD			1.032*
			(0.425)
Built 1940s	-12.58	-18.70	19.92
	(14.66)	(12.81)	(10.70)
Built 1950s	101.0*	-55.89*	-16.29
	(11.84)	(10.59)	(8.846)
Built 1960s	313.9*	-69.04*	-29.21*
	(12.02)	(11.02)	(9.253)
Built 1970–1974	399.0*	-75.25*	-14.52
	(14.03)	(12.76)	(10.68)
Built 1975–1977	548.3*	-36.30*	27.33*
	(16.12)	(14.52)	(12.10)
Built 1978–1982	533.6*	-89.07*	14.60
	(14.42)	(13.16)	(11.04)
Built 1983–1992	548.6*	-159.9*	-28.18*
	(12.19)	(11.41)	(9.618)
Built 1993–1997	483.1*	-320.7*	-144.8*
	(15.73)	(14.45)	(12.12)
Built 1998–2000	516.8*	-316.9*	-176.9*
	(16.46)	(15.31)	(12.93)
Built 2001–2004	511.9*	-395.9*	-189.1*
	(17.95)	(16.81)	(13.86)
Built 2005–2008	538.6*	-399.8*	-294.6*
	(23.25)	(21.50)	(17.27)
CDD × built 1940s	0.954*	0.929*	-0.179
	(0.199)	(0.173)	(0.614)
CDD × built 1950s	0.692*	1.058*	0.329
	(0.156)	(0.136)	(0.498)
CDD × built 1960s	0.838*	1.112*	0.906
	(0.157)	(0.138)	(0.504)
CDD × built 1970–1974	1.278*	1.585*	2.164*
	(0.179)	(0.157)	(0.595)
CDD × built 1975–1977	1.133*	1.582*	0.589
	(0.198)	(0.173)	(0.653)
CDD × built 1978–1982	1.753*	2.352*	1.080
	(0.172)	(0.151)	(0.592)
CDD × built 1983–1992	2.189*	2.754*	1.362*
	(0.152)	(0.134)	(0.505)
CDD × built 1993–1997	2.905*	3.549*	2.504*
	(0.181)	(0.159)	(0.637)
CDD × built 1998–2000	2.465*	2.925*	0.596
	(0.192)	(0.169)	(0.670)
CDD × built 2001–2004	2.822*	3.453*	0.645

	(0.185)	(0.163)	(0.647)
CDD × built 2005–2008	1.065*	1.930*	-0.710
	(0.206)	(0.180)	(0.739)
ln(square feet 1000s)		793.8*	786.2*
		(7.439)	(7.443)
Bedrooms		66.39*	67.88*
		(3.195)	(3.197)
Electric stove		-80.25*	-81.82*
		(6.018)	(6.021)
Electric oven		189.7*	188.5*
		(5.572)	(5.575)
Remodeled		64.49*	66.48*
		(5.704)	(5.707)
ln(years at address)		89.92*	94.59*
		(2.997)	(3.001)
ln(number of residents)		502.0*	502.1*
		(4.658)	(4.661)
ln(household income)		202.6*	206.0*
		(3.383)	(3.386)
Residents aged 0–5		-101.2*	-100.7*
		(3.386)	(3.388)
Residents aged 65–99		-67.93*	-66.66*
		(2.907)	(2.909)
Household head graduated college		-147.6*	-145.0*
		(4.646)	(4.650)
Disabled resident		303.5*	304.7*
		(6.912)	(6.916)
Household head Black		64.43*	71.56*
		(11.79)	(11.80)
Household head Latino		-176.1*	-175.8*
		(6.590)	(6.595)
Own home		-208.2*	-212.0*
		(8.517)	(8.523)
Central AC		418.2*	405.2*
		(5.011)	(5.023)
Room AC		167.3*	156.2*
		(6.787)	(6.788)
Refrigerators		15.19*	15.56*
		(0.762)	(0.763)
Freezers		0.392*	0.413*
		(0.149)	(0.150)
RASS 2009		26.62*	31.59*
		(4.997)	(5.006)
12-month fixed effects	yes	no	no
County–month fixed effects	no	yes	yes
Observations	259,007	259,007	259,007
R-squared	0.143	0.363	0.362

Heteroskedastic-consistent standard errors in parentheses. (Standard deviations in first column.) In column (3), the interaction coefficients ("CDD x built 19xx") correspond to interactions with the difference between monthly CDD and the monthly average CDD. Source: Residential Appliance Saturation Study 2003 and 2009.

Table A5.
Comparing California to Other States

	Averages	Electricity (MBTU)	Total energy (MBTU)
	(1)	**(2)**	**(3)**
California	0.104	-15.71*	-22.64*
	(0.306)	(1.402)	(3.097)
ln(square feet)	0.762	6.036*	20.96*
	(0.515)	(0.455)	(1.034)
Rooms	6.472	1.946*	7.686*
	(1.760)	(0.208)	(0.348)
ln(household size)	0.909	12.25*	15.96*
	(0.536)	(0.409)	(0.899)
ln(household income) ($2010)	10.75	1.398*	4.073*
	(0.825)	(0.231)	(0.482)
Children ≤12 yrs old[a]	0.570	-1.774*	-0.864
	(0.979)	(0.232)	(0.496)
Seniors ≥65 years old	0.358	-1.259*	1.615*
	(0.656)	(0.326)	(0.619)
Own home	0.867	0.160	-5.201*
	(0.340)	(0.462)	(1.018)
Central AC	0.518	6.253*	6.703*
	(0.500)	(0.378)	(0.903)
Refrigerators	1.265	5.457*	5.335*
	(0.483)	(0.445)	(0.881)
Heating degree days (×100)	43.58	0.00300	0.477*
	(22.27)	(0.0185)	(0.0533)
Cooling degree days (×100)	13.62	0.248*	-0.0813
	(9.969)	(0.0362)	(0.0791)
Constructed 1940s	0.0792	0.726	-2.347
	(0.270)	(0.708)	(1.778)
Constructed 1950s	0.160	-0.367	-3.825*
	(0.366)	(0.533)	(1.431)
Constructed 1960s	0.136	1.356*	-9.588*
	(0.343)	(0.607)	(1.480)
Constructed 1970s	0.155	6.345*	-22.10*
	(0.362)	(0.643)	(1.520)
Constructed 1980s	0.136	4.605*	-27.12*
	(0.342)	(0.644)	(1.514)
Constructed 1990s	0.0935	1.775*	-25.93*
	(0.291)	(0.678)	(1.576)
Constructed 2000s	0.0488	0.593	-27.13*
	(0.215)	(0.818)	(1.843)
Constructed 1940s in CA	0.00692	0.964	11.16*
	(0.0829)	(1.673)	(4.223)
Constructed 1950s in CA	0.0160	-0.300	6.328*
	(0.126)	(1.196)	(2.879)
Constructed 1960s in CA	0.0124	-3.115*	6.345*
	(0.111)	(1.268)	(3.057)
Constructed 1970s in CA	0.0114	-4.482*	13.72*
	(0.106)	(1.394)	(3.148)
Constructed 1980s in CA	0.0121	-4.408*	12.06*
	(0.109)	(1.404)	(3.329)
Constructed 1990s in CA	0.00788	-2.294	14.65*
	(0.0884)	(1.537)	(3.471)

Constructed 2000s in CA	0.00329 (0.0572)	5.019 (4.244)	28.52* (8.571)
5 RECS survey year fixed effects		✓	✓
9 census division fixed effects		✓	✓
Observations	20,544	20,544	20,544
R-squared		0.346	0.346

Heteroskedastic-consistent standard errors in parentheses. (Standard deviations in first column.)
Source: Residential Energy Consumption Survey (RECS) 1993–2009.
[a] Children are defined as ≤14 years old in RECS 2009.