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Drivers of U.S. Household Energy Consumption, 1980-2009

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Introduction

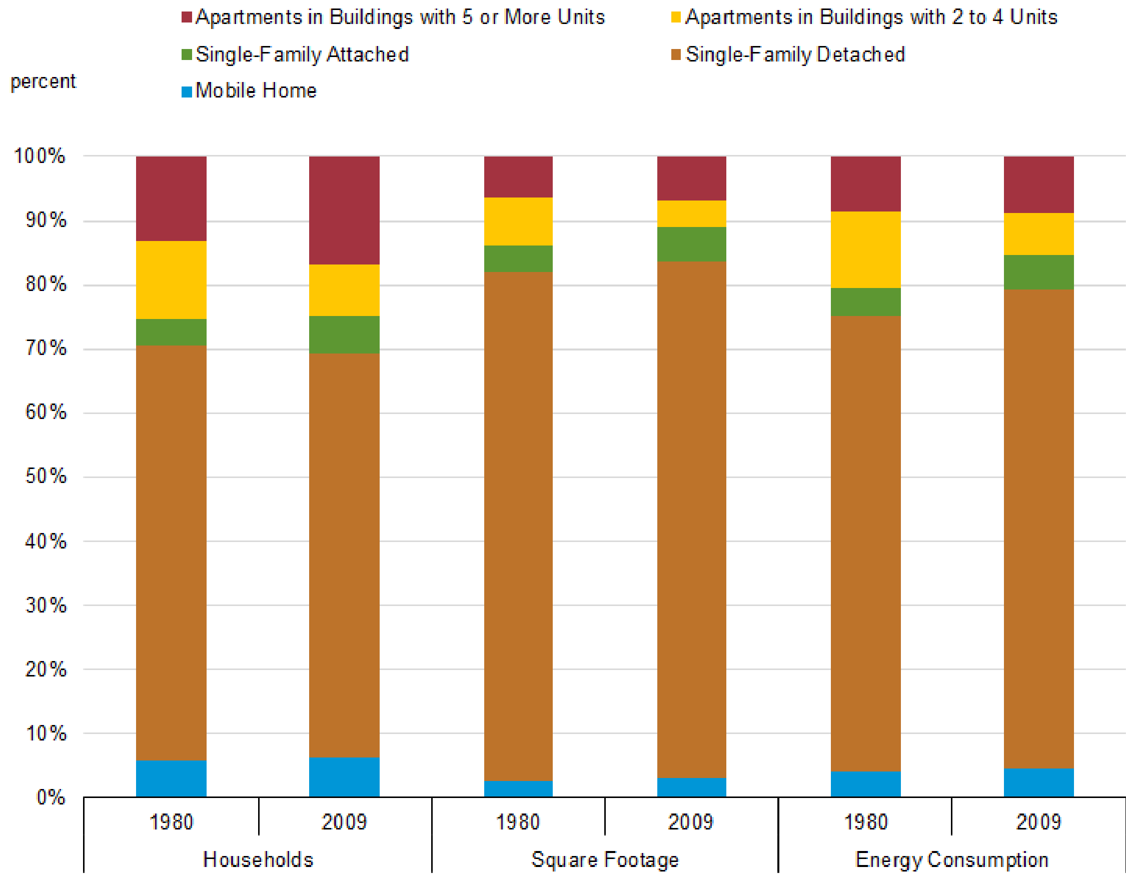
In 2012, the residential sector accounted for 21% of total primary energy consumption and about 20% of carbon dioxide emissions in the United States (computed from EIA 2013). Because of the impacts of residential sector energy use on the environment and the economy, this study was undertaken to help provide a better understanding of the factors affecting energy consumption in this sector. The analysis is based on the U.S. Energy Information Administration's (EIA) residential energy consumption surveys (RECS) 1980-2009.[1]

According to RECS, U.S. households used 10.2 quadrillion Btu (quad) of site energy in 2009.[2] During the 1980-2009 time period, household site energy increased by 0.9 quads or 8.9%—an average annual growth of 0.3%. Over the same period, the number of households increased by 33.0% and total floor space[3] by 52.0%. This is equivalent to an average annual growth of 1.1% and 1.8%, respectively. As a result, the aggregate energy intensity per household and per square foot declined by 24.2% and 43.1%, respectively.[4]

The change in aggregate energy intensity was affected by other factors such as structural changes and fluctuation in weather. We applied decomposition techniques to separate the effects of these factors on aggregate energy intensity. More specifically, our decomposition identified four main categories affecting energy use: activity, structural changes, intensity, and weather effects.[5] Activity was specified as the number of households. Structural changes were the shifts in the mix of housing types, the regional distribution of households, and the average floor space per household. Intensity was the ratio of energy consumption to square foot of living area, and weather reflected energy impacts related to heating- and cooling-season weather variability (Hojjati and Wade, 2012).

[1] RECS is most recently available for the year 2009.
[2] The Btu value of energy at the point of delivery to the home, building, or establishment, is referred to as "delivered" or "site" energy. It does not include losses that occur in the generation, transmission, and distribution of energy. The analysis of energy consumption in this paper is based on "site" energy consumption.
[3] Total floor space includes attached garages, basements, and finished heated/cooled attics.
[4] All reported percentage changes are logarithmic to be consistent with the decomposition of energy changes into separate effects.
[5] Factors such as conservation effort and consumer responses to change in energy prices may also influence changes in energy intensity. These additional factors are not considered in the decomposition analysis.

Figure 1. Distribution of households, total square footage, and energy consumption by housing type, 1980 and 2009



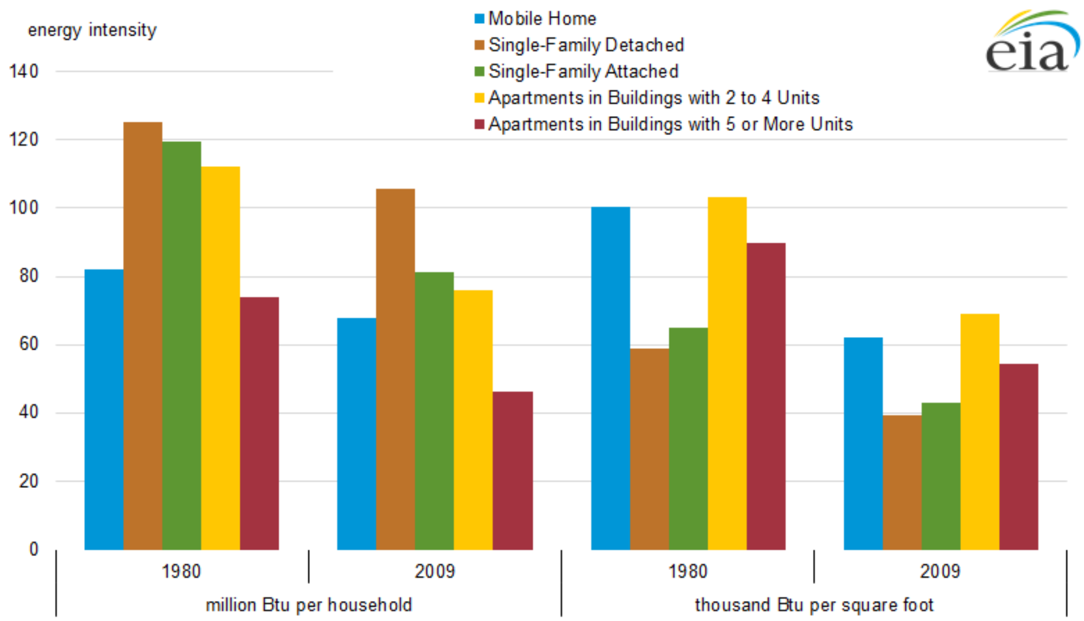
Sources: Hojjati and Wade (2012) and U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980 and 2009.

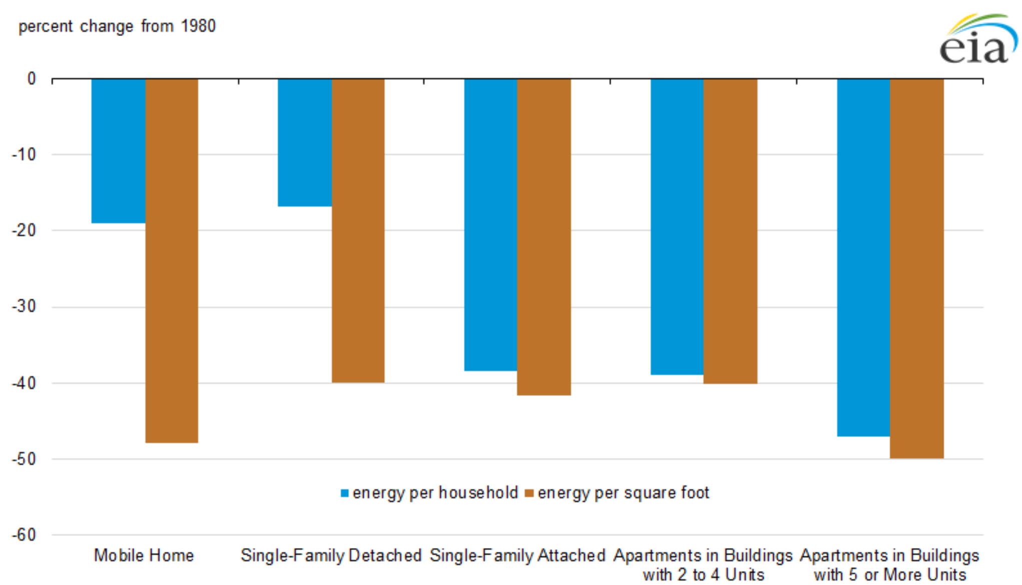
Type of housing

The majority of homes in the United States are single-family units (both attached and detached), accounting for about 69.1% of the housing, about 85.9% of floor space, and 80.0% of site energy consumption in 2009 (Figure 1). The remaining housing units in 2009 were apartments and mobile homes, accounting for 24.8% and 6.1%, respectively. However, over the 1980-2009 period there was a shift away from detached single-family homes and apartments in smaller buildings to attached single-family homes and apartments in larger buildings. *Ceteris paribus*[6] , the change in housing-type mix was expected to affect household energy consumption because energy consumption per square foot or per household varied by type of housing unit (Figure 2). Energy consumption per household was greatest for a single-family detached home. However, because of the larger size of average single-family detached homes, energy consumption per square foot was least for this type of housing unit.

[6] Refers to conditions where all other factors are equal.

Figure 2. Energy consumption intensity by type of housing: 1980 and 2009 and percentage change from 1980



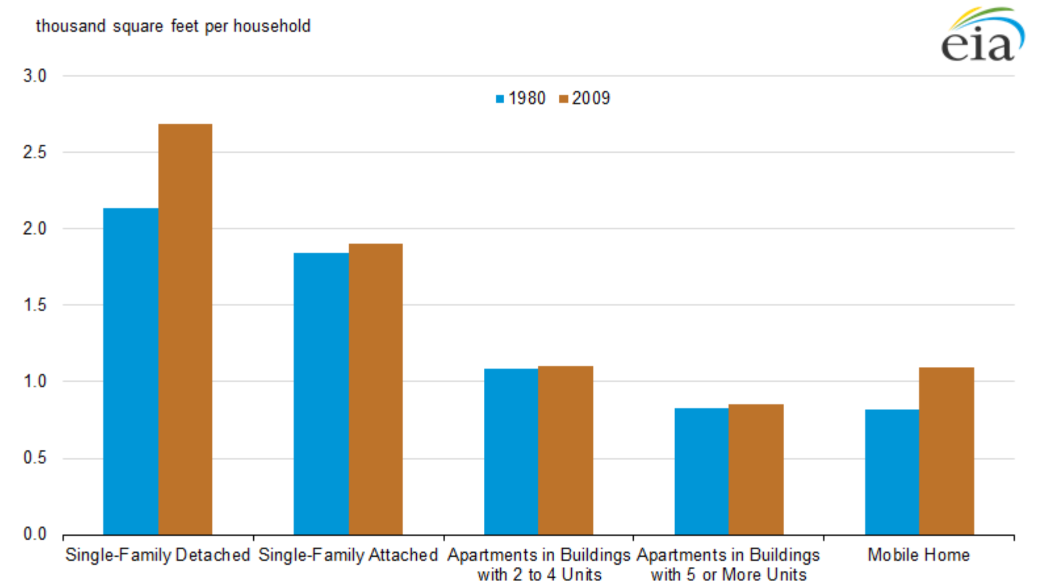


Sources: Hojjati and Wade (2012) and U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980 and 2009.

Size effect

There was a close relationship between the type and size of a home (Figure 3). During the 1980-2009 time period, the average size of a U.S. home increased by 18.9%. There were also significant variations in growth by housing-type (Figure 4). The average size of single-family detached homes grew faster than other housing types.

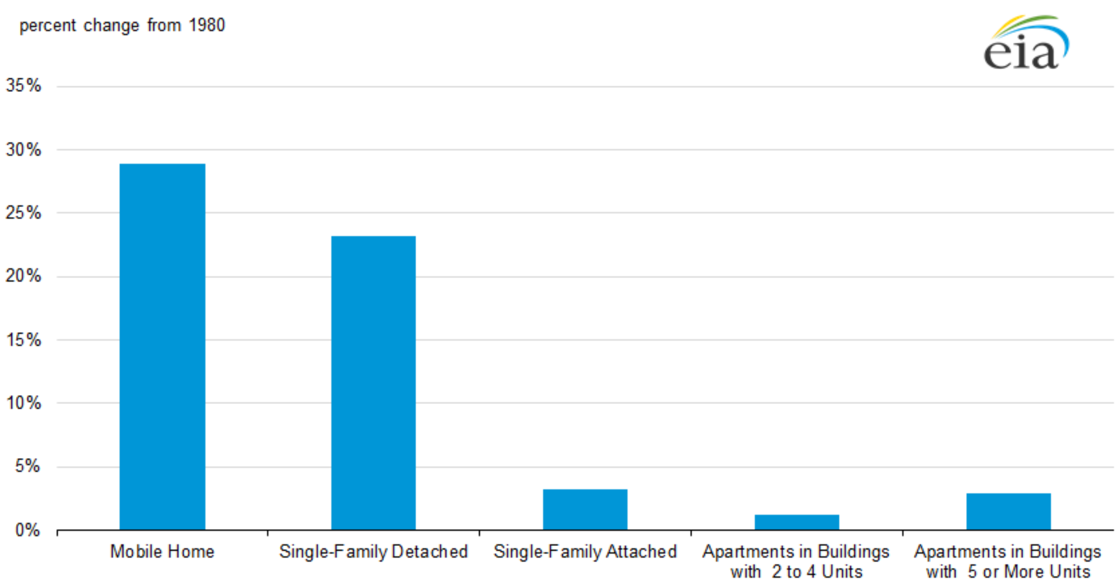
Figure 3. Average size of homes by housing-type 1980 and 2009



Sources: Hojjati and Wade (2012) and U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980 and 2009.

In 2009, the average square footage was 2,688 square feet for detached single-family, 1,899 square feet for attached single-family, 1,100 for apartments in 2-4 units, 849 for apartments in 5 or more units, and 1,092 square feet for mobile homes. On a per square foot basis, single-family homes were less energy intensive than apartment and mobile homes. However, the reverse was true on a per household basis (Figure 2). The structural change in the mix of housing types was expected to affect aggregate energy intensity. Because cooling and heating uses are sensitive to the size of home, intensity was defined as energy consumption per square foot in the decomposition analysis.

Figure 4. Growth in average living space per household by housing type, 1980-2009

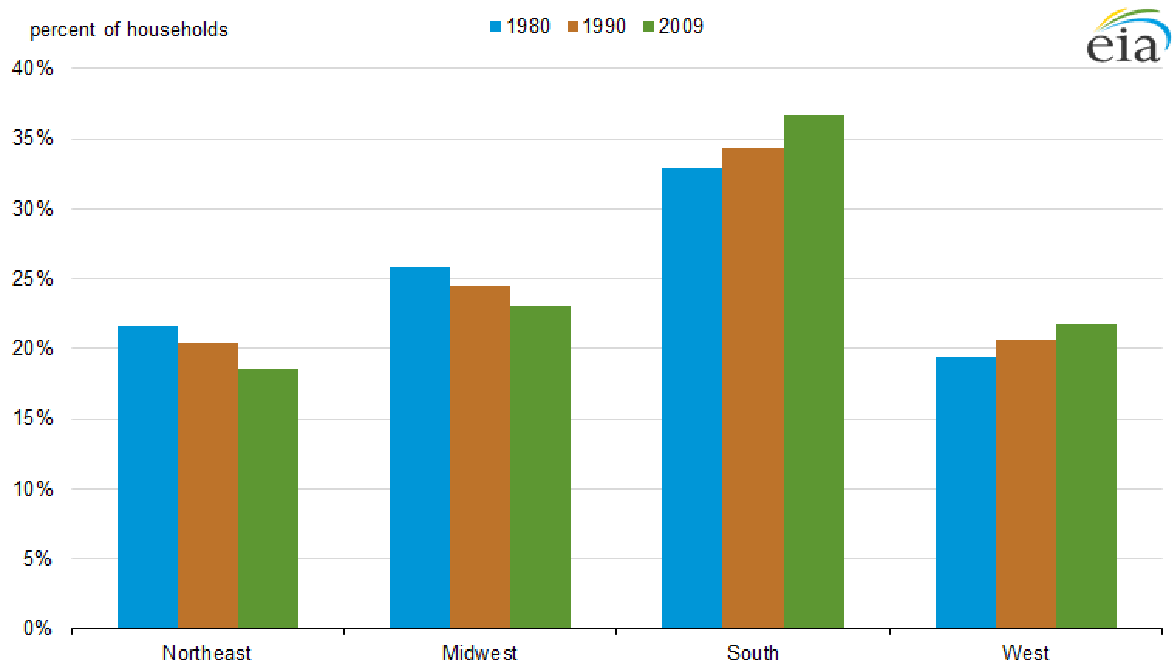


Sources: U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980 and 2009.

Regional effect

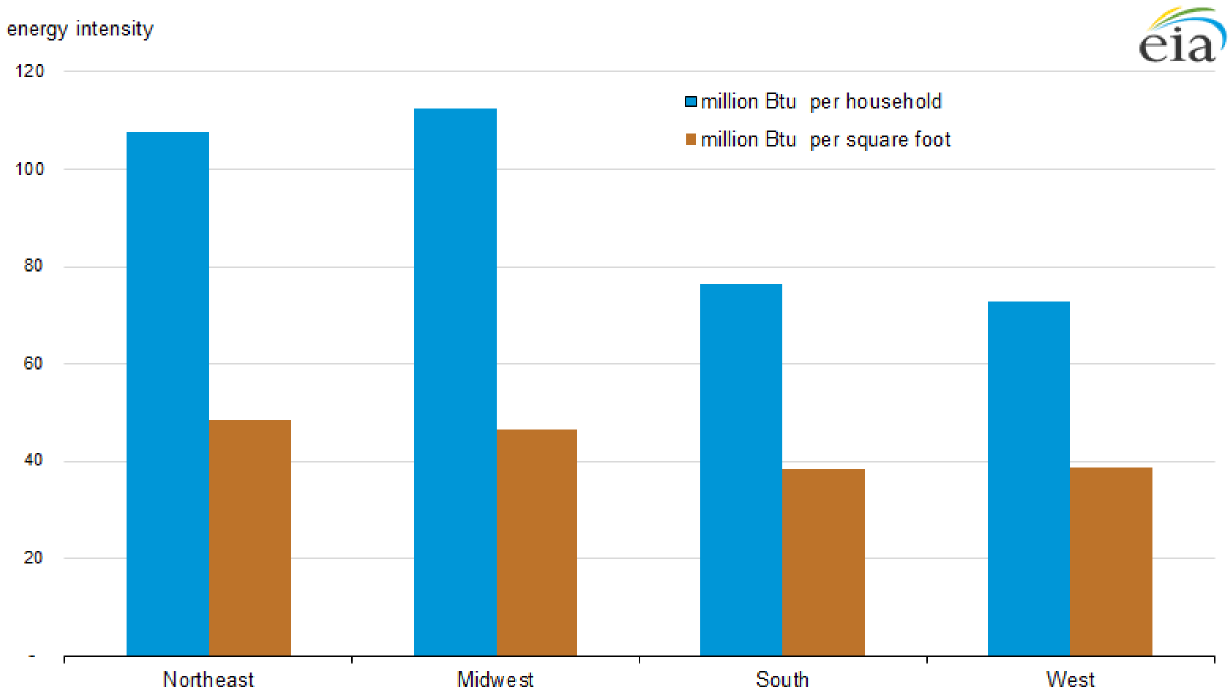
Over the 29-year period, household shares have shifted from the Northeast and the Midwest to warmer regions in the South and West, where demand for space heating is less than for space cooling (Figure 5). The number of households in the South and the West increased by 44.6% and 44.3%, respectively, resulting in a lower demand for space heating. The regional shifts in population have implications for aggregate energy intensity since energy consumption per household and per square foot were lower than in the Northeast and Midwest regions (Figure 6). Thus, it was important to separate the impact of a shift in the regional distribution of households when decomposing factors affecting aggregate energy intensity.

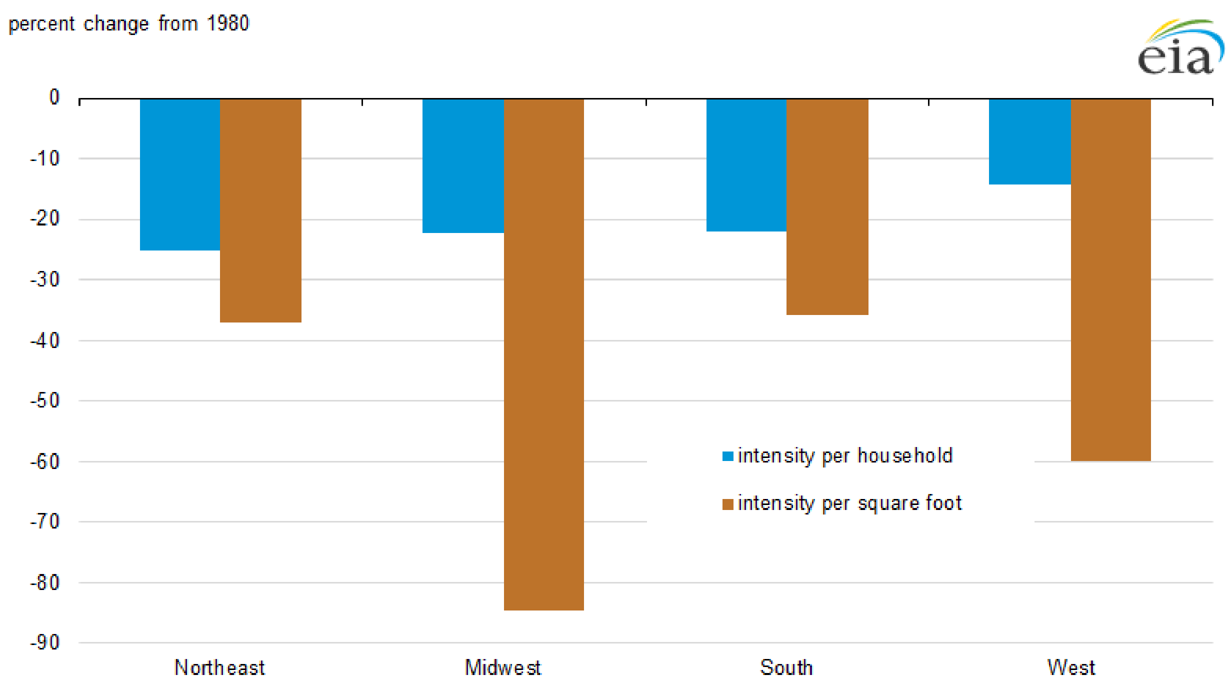
Figure 5. Household distribution by Census regions, 1980, 1990, and 2009



Sources: Hojjati and Wade (2012) and U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980 and 2009.

Figure 6. Aggregate Energy Consumption Intensity by Census region in 2009 and percent change from 1980





Sources: U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980 and 2009.

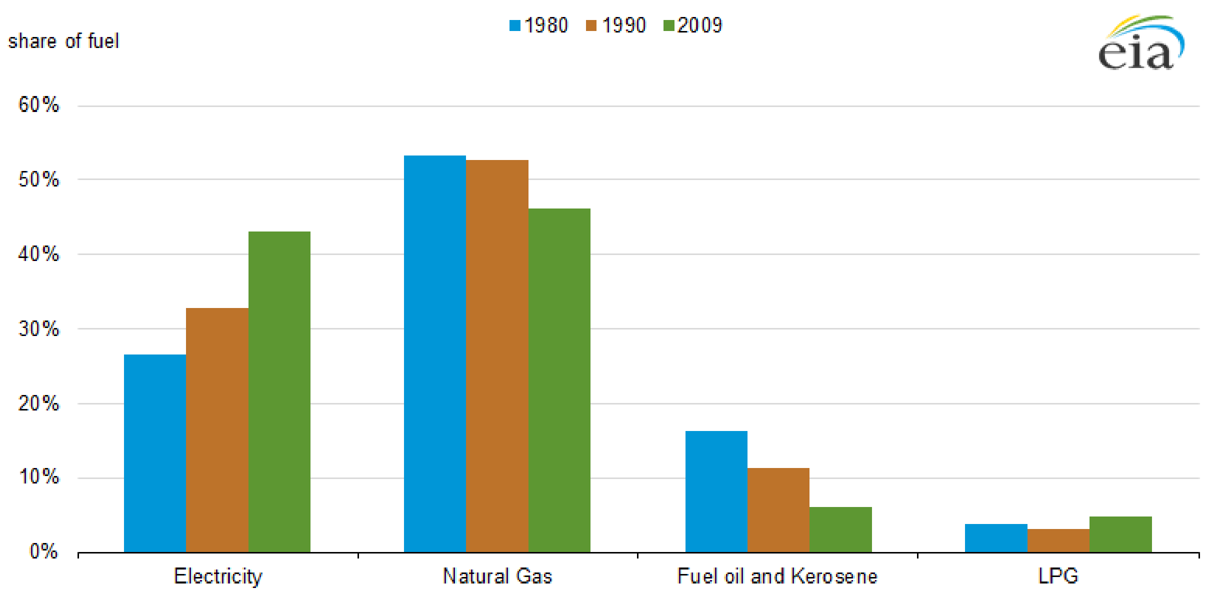
Weather effect

Weather is the key factor causing annual fluctuation in energy consumption associated with space heating and cooling demand. The summer of 2009 was cooler and the winter of 2009 was warmer than during 1980. The average number of cooling degree days (CDD) and heating degree days (HDD) declined by 6.6% and 4.7%, respectively. Therefore, we expected weather to impact the changes in energy consumption in our decomposition analysis.

Energy type change

Over the 29 years from 1980 to 2009, there has been a shift in the mix of energy types, although natural gas remained the main energy source (Figure 7). The share of natural gas decreased from 53.3% in 1980 to 46.1% in 2009, while the share of electricity increased from 26.6% to 43.1%.

Figure 7. Distribution of fuel sources in U.S. households 1980, 1990, and 2009



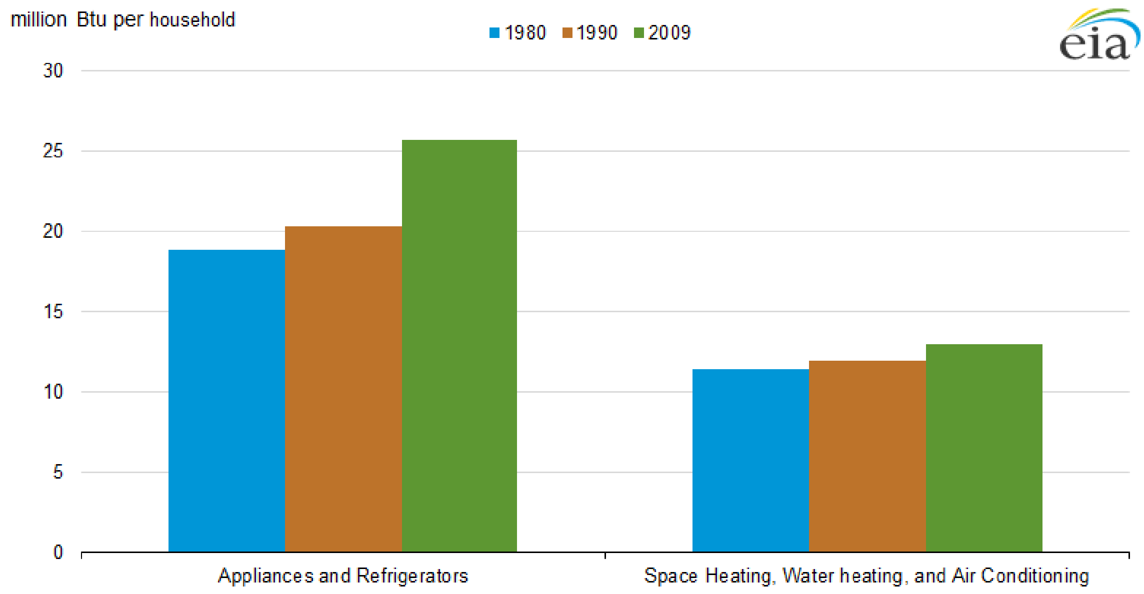
Sources: Hojjati and Wade (2012) and U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980 and 2009.

Appliances account for the largest share of household electricity consumption, and that share is increasing (Figure 8).[7] During this time period the electricity consumption per household for appliances (including refrigerators) increased by 30.6%. For key end uses, i.e., space heating, water heating, and air conditioning, the increase in electricity consumption was less than one-fourth of the increase in appliances due to substitution from other fuels. However, the strongest growth was in end uses with less penetration, i.e., microwave ovens, personal computers[8], central air conditioning, and clothes dryers (Figure 9).

[7] The 1980 RECS did not estimate energy consumption for refrigerators, the estimate for 1980 appliances includes energy consumption for refrigerators. In order to compare appliance consumption for 1980 with appliance consumption for 2009, the consumption for refrigerators and appliances are combined.

[8] The early years of RECS did not survey personal computers since they were so uncommon.

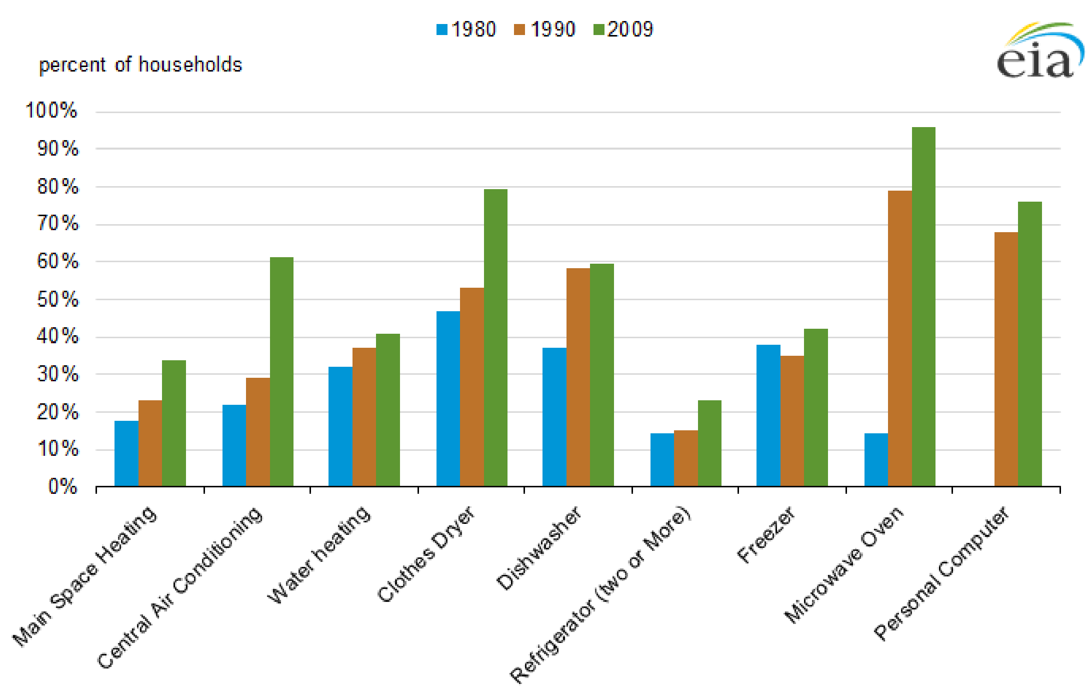
Figure 8. Electricity intensity consumption per household by end uses, 1980, 1990, and 2009



Sources: U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980,1990, and 2009.

Intensity effects were expected to vary by fuel type. To this end, we present separate decompositions for total energy, electricity, and natural gas consumption for space heating.

Figure 9. Penetration of selected electrical appliances in U.S. households, 1980, 1990, and 2009



Sources: Hojjati and Wade (2012) and U.S. Energy Information Administration, Residential Energy Consumption Surveys, 1980, 1990, and 2009.

Results

We used the Log Mean Divisa Method (LMDI- II) decomposition technique described in Appendix A to analyze the contribution of the component factors to changes in residential energy consumption between 1980 and 2009. The same method was used to analyze changes in the two main residential fuels, i.e., electricity consumption, and space heating natural gas consumption. The study period was then separated into three sub-periods and the decomposition analysis was repeated to better understand the changes in consumption.

Decomposition of national effects for 1980–2009

Total energy

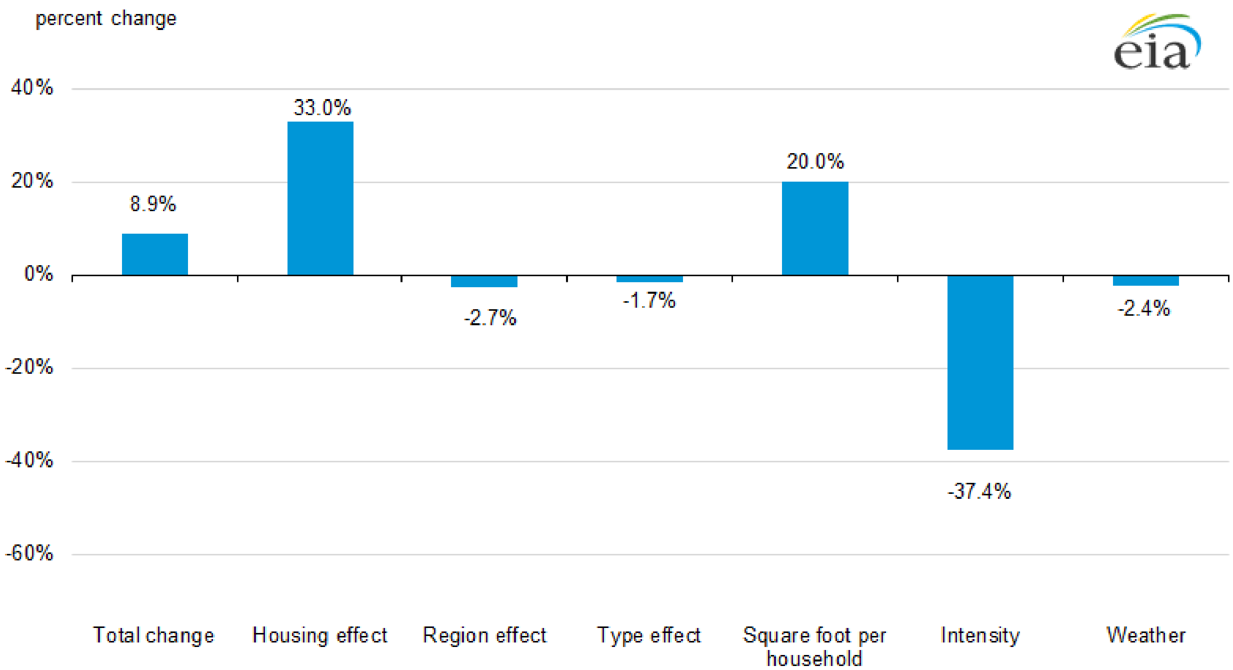
Figure 10 provides the results of decomposition analysis at the national level for the 1980 to 2009 period during which household energy consumption increased by 8.9%. It shows that two factors operated strongly to increase energy consumption – the number of housing units and the average size of homes. The decomposed effect of housing units using LMDI-II (33.0%) equals the aggregate growth in the number of households over the time period. However, because of structural effects (i.e., change in housing-type mix and regional distribution) the decomposed impact of average living space per household (20.0%) was higher than the calculated growth in average living space from aggregate data (18.9%).

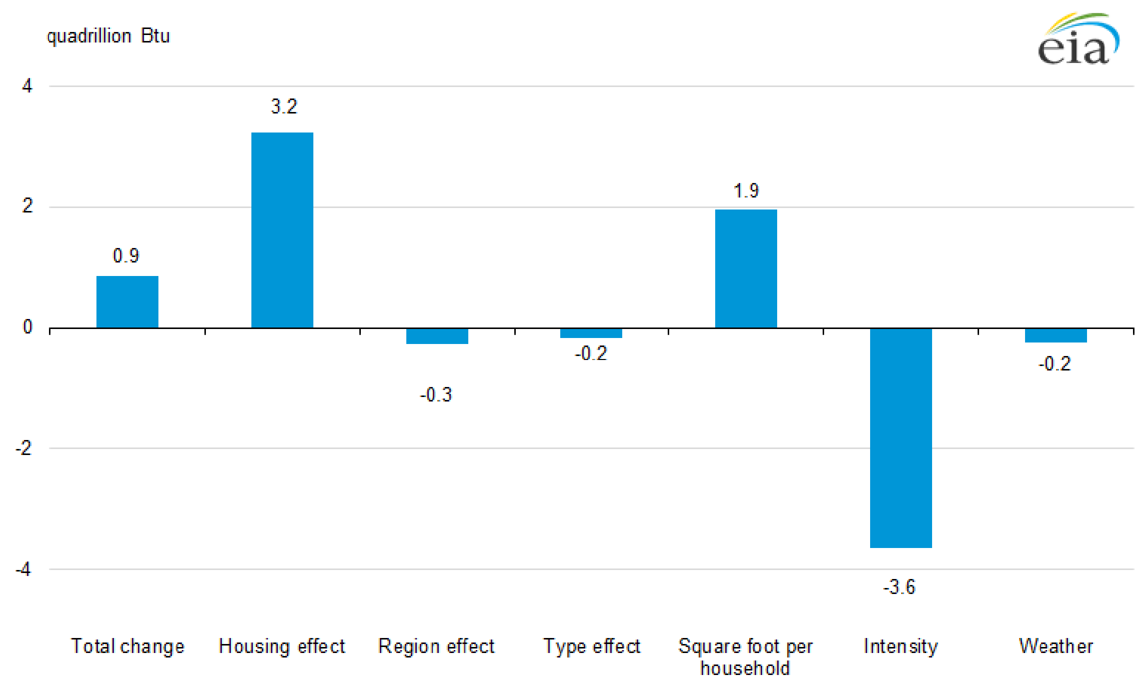
The main source of reduction in total energy consumption was the 37.4% decline in intensity per square foot which was less than the decline in aggregate energy per square foot (43.1 %). This difference was due to changes in regional distribution and housing-type mix as well as fluctuations in weather. [9]

The regional distribution and housing-type mix as well as weather had minor effects in reducing energy consumption per square foot. The primary structural effect was the change in regional distribution of housing, which explained the 2.7% reduction in energy consumption due to population movement (region effect) to regions with lower heating demands. The other structural effect was the type mix of households within Census regions, which explained 1.7% of the consumption reduction seen over this period (Figure 10). The weather effect resulted in a reduction in energy use of 2.4% over the 1980-2009 period as a result of the warmer winter and cooler summer in 2009 relative to 1980.

[9] Energy intensity per square foot also can be affected by energy prices and market conditions as well as consumer preferences, residential appliance standards, building codes, incentives, energy labeling, and other informational programs.

Figure 10. Decomposition of change in total energy consumption, 1980-2009





Sources: U.S. Energy Information Administration, Residential Energy Consumption Surveys (1980 and 2009) and Monthly Energy Review 2013.

Households consumed 10.2 quad of energy in 2009, but according to our estimate from decomposition analysis, they would have used 13.8 quad without improvements in energy consumption per square foot since 1980 (Figure 10).

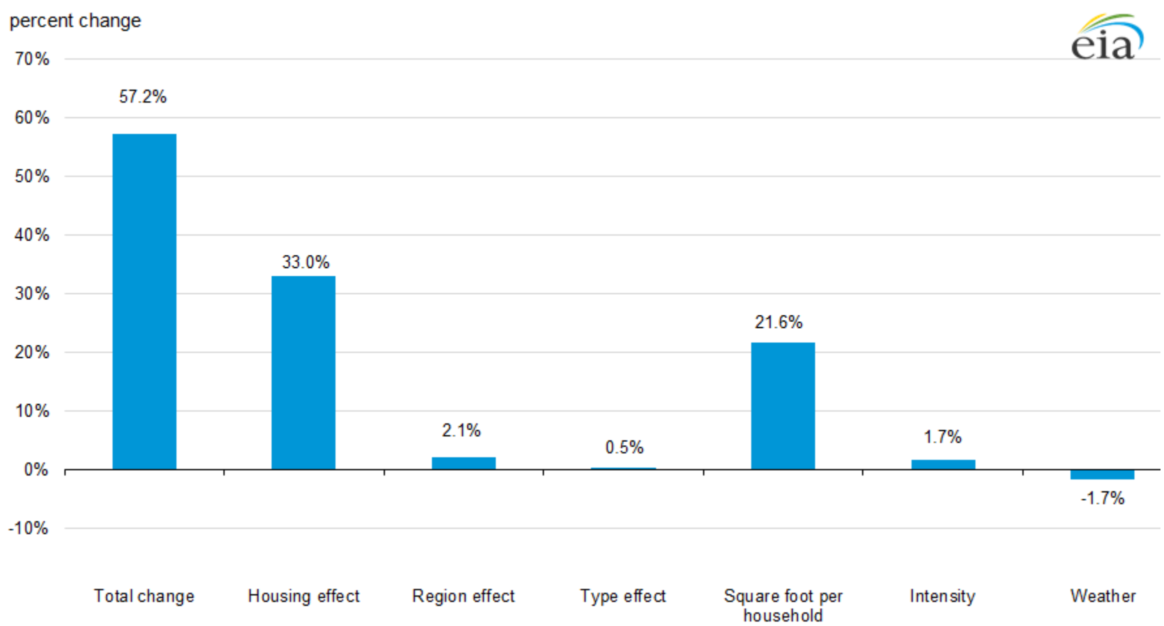
Total electricity

Over the period of study, demand for electricity grew over 6 times faster than total energy consumption (Figure 11). Electricity consumption increased by 57.2% while total energy increased by 8.9%. Similar to total site energy consumption, growth in the number of housing units and the size of homes had a significant impact on the rise in electricity consumption.

The impact of intensity of electricity use per square foot was positive and less significant (1.7%) compared with the decline of 37.4% for total energy consumption. The regional effect was responsible for a 2.1% increase in electricity consumption whereas this impact was a negative 2.7% for total site consumption. The weather effect was negative, as it was for total site energy, but smaller reflecting the numerous non-weather-sensitive electric end uses.

Despite improvements in energy efficiency standards for various household appliances, the decomposed intensity of electricity per square foot has increased over the study period as more electrical end uses have penetrated. This was partially due to the purchase of new appliances and an increase in the number of end uses.

Figure 11. Decomposition of change in electricity consumption, 1980-2009



Sources: U.S. Energy Information Administration, Residential Energy Consumption Surveys (1980 and 2009) and Monthly Energy Review 2013.

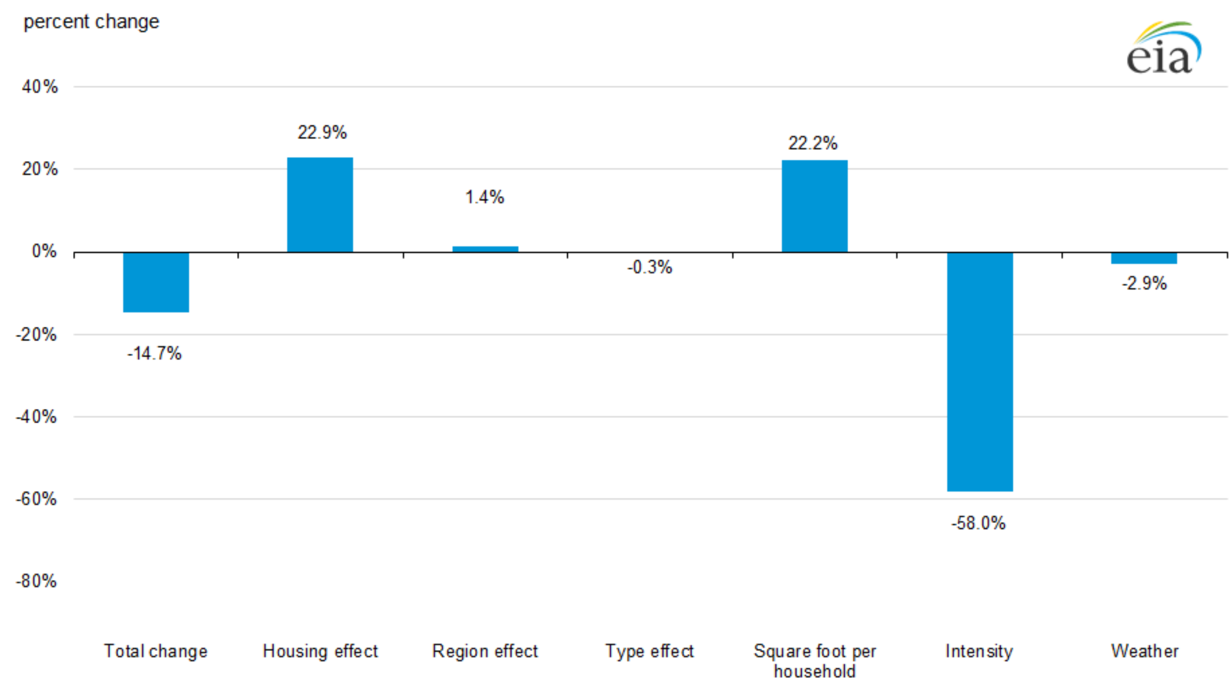
Natural gas

The analysis of natural gas was based on households that used natural gas for space heating. Natural gas is the main fuel used for space heating and this end use accounted for 62.7% of total household natural gas consumption in 2009. The aggregate intensity (the ratio of space heating natural gas to floor space) declined by 65.1% over the 1980-2009 period.

Natural gas consumption for space heating declined by 14.7% over the period (Figure 12). The number of housing units and the size of homes were two significant factors, ceteris paribus, that positively affected natural gas consumption. The decline in natural gas consumption was almost entirely due to the 58.0% decline in intensity over the 1980-2009 period, which more than offset the impacts of housing, region, and floor area, which all would have otherwise increased natural gas consumption. The decline in intensity was more than one-and-a-half times the decline for total site consumption. As expected, given that natural gas is primarily a heating and water heating fuel, weather was more significant than in either of the previous energy decompositions and was consistent with the 4.7% decline in HDD.

The decline in natural gas intensity was mainly the result of improvements in the efficiency of household space heating units and building codes as well as an increase in natural gas prices. The annual fuel utilization efficiency (AFUE) of a standard furnace increased by more than 13 percentage points over the period of study (Consumer Reports, 2014).[10] The 26.7% increase in real natural gas prices over this period may have led to replacement with heating equipment using other fuels (reducing the number of households heated by natural gas). This price increase could have also resulted in the purchase of gas equipment more efficient than the 78% AFUE standard – currently units as high as 97% AFUE (Consumer Reports, 2014) are available, albeit at a cost and installation premium.

Figure 12. Decomposition of change in space heating natural gas consumption, 1980-2009



Sources: U.S. Energy Information Administration, Residential Energy Consumption Surveys (1980 and 2009) and Monthly Energy Review 2013.

[10] A standard gas furnace in the 1970s had an annual fuel utilization efficiency (AFUE) of 65%. Effective on January 1, 1992, the minimum AFUE was set to 78%.

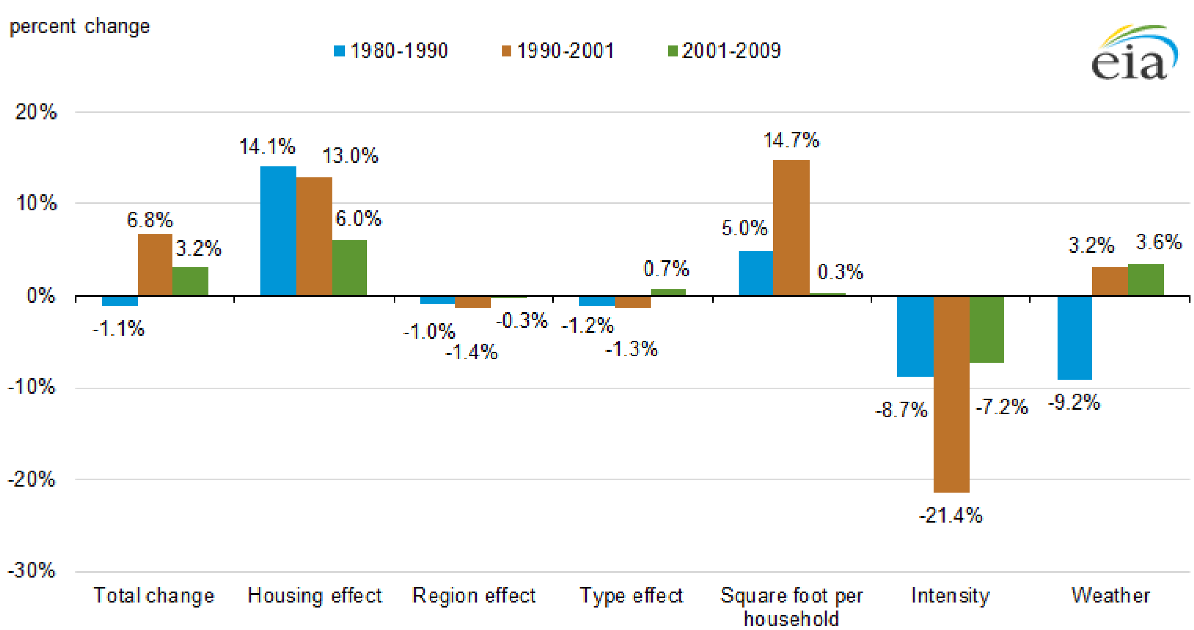
Decomposition of national effects changes for sub-periods 1980-1990, 1990-2001, and 2001-2009

To better understand the changes in energy consumption, the study period was separated into three sub-periods: 1980-1990[11] , 1990-2001, and 2001-2009. The selection of sub-periods was motivated by the influence of energy efficiency programs while having approximately equal intervals. The post-1990 sub-period reflects the impact of Federal energy efficiency standards and demand-side management as well as ENERGY STAR® and other energy efficiency programs.

Total energy

Change in energy consumption was significantly different across the three sub-periods (Figure 13). Energy consumption decreased by 1.1% between 1980 and 1990 but increased by 6.8% and 3.2% during the 1990-2001 and 2001-2009 sub-periods, respectively. The growth of energy in the first sub-period from increases in the number of households and housing unit size (19.1%) was offset by decreases in energy intensity, weather, regional distribution, and housing-type (20.2%). The growth in energy consumption between 1990 and 2001 was faster than the other sub-periods, even though energy intensity declined over two times faster in percentage terms than in the other two sub-periods. The impact of weather on energy growth was negative in the first sub-period, whereas it was positive during the last two sub-periods because the summer and winter of 1990 relative to 1980 were cooler and warmer than in the 1990-2001 and 2001-2009 sub-periods, respectively.

Figure 13. Decomposition of total energy changes for sub-periods, 1980-1990, 1990-2001, and 2001-2009



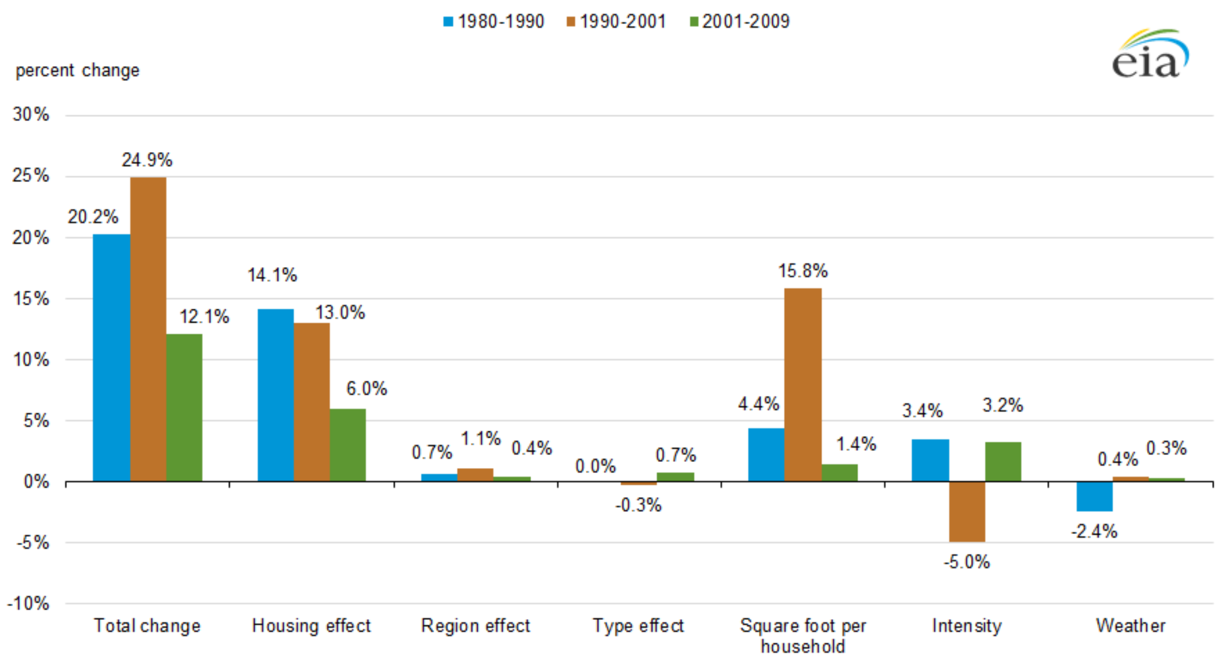
Sources: Hojjati and Wade (2012), U.S. Energy Information Administration, Residential Energy Consumption Surveys (1980, 1990, 2001, and 2009) and Monthly Energy Review 2013.

[11] The source for all decomposition estimates for the 1980-1990 sub-period is Hojjati and Wade 2012.

Total electricity

Electricity consumption in 1990-2001 grew faster than in the other periods, 23% faster than the change for 1980-1990 and more than twice as fast as the change for 2001-2009 (Figure 14). Contrary to the other two sub-periods, energy intensity in the 1990-2001 sub-period declined. However, this decline was less than one-fourth as much as it was for household total site energy consumption. Also, during the same period, the average size of living area increased faster than the other two sub-periods. As expected, the impact of weather was less than in the previous case, as many household electric end uses are not sensitive to variations in weather.

Figure 14. Decomposition of total U.S. household electricity consumption changes for sub-periods, 1980-1990, 1990-2001, and 2001-2009



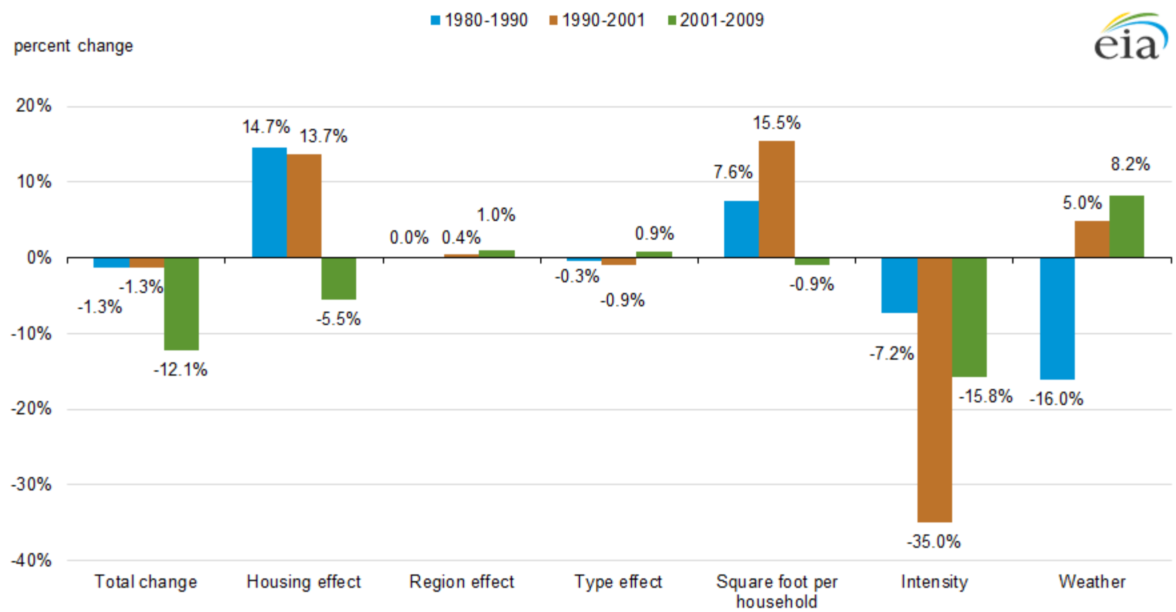
Sources: Hojjati and Wade (2012), U.S. Energy Information Administration, Residential Energy Consumption Surveys (1980, 1990, 2001, and 2009) and Monthly Energy Review 2013.

Natural gas

Contrary to the total energy and electricity cases, natural gas consumption for space heating declined during the 1990-2001 and 2001-2009 sub-periods (Figure 15). Natural gas consumption declined more than nine times faster than in the first two sub-periods. This consumption decline in 2001-2009 was affected by the decline in intensity, housing units using gas, and average size of living space over this sub-period, which more than offset increases due to the impact of any other factors. A striking contrast to the total energy and electricity cases is the decline in the number of housing units over the 2001-2009 sub-period, representing shifts away from natural gas space heating. Also during this sub-period, the average size of gas-heated homes decreased compared with homes using other heating fuels.

Weather effects showed the same pattern as in the total energy and electricity cases. However, these effects were more significant than for the other two cases, mainly due to the focus on space heating consumption.

Figure 15. Decomposition of space heating natural gas consumption changes for 1980-1990, 1990-2001, and 2001-2009



Sources: Hojjati and Wade (2012), U.S. Energy Information Administration, Residential Energy Consumption Surveys (1980, 1990, 2001, and 2009) and Monthly Energy Review 2013.

Summary

The main purpose of this report was to help in understanding the changes in U.S. households' energy consumption between 1980 and 2009 using available RECS survey data. We estimated three decompositions for total energy, total electricity, and natural gas used for space heating.

We found that over the total interval for all three cases, changes in the number of housing units and average size of homes resulted in increases in energy consumption. We also found that for both total energy and natural gas space heating consumption, the decline in energy intensity was the main reducing factor. The results further revealed that the decline in total energy intensity was largely due to a larger decline in intensity of natural gas for space heating.

For the entire period, the results were mixed with respect to region and housing-type effects. Also, changes in weather led to a reduction in the growth of household energy consumption over the study period.

The analysis of sub-periods 1980-1990, 1990-2001, and 2001-2009 revealed that in all three decompositions, the largest decline in energy intensity occurred during the 1990-2001 sub-period. This may be a reflection of post 1990 appliance standards, building codes, and other energy efficiency programs, which all acted to intensify the decline in energy intensity during this period.

The decline in energy intensity during the 2001-2009 sub-period was smaller than during the 1990-2001 sub-period. We are not able to explain this difference in intensity growth based on the analysis in this study. Possible explanations could be further penetration of electricity-using appliances, the cycling through of some of the existing standards, lifestyle changes, and price and efficiency rebound effects, to name a few. Annual panel data may be a way to address some of these questions, but we are unaware of the availability of any such national panel data sets.

Appendix A

The decomposition methodology used in this report is based on Hojjati and Wade (2012). Using the logarithmic mean Divisia method, introduced by Ang and Choi (1997), they estimated the percentage change in total energy consumption for each Census region[12] by the following expression:

$$\ln\left(\frac{E_t}{E_0}\right) = \sum_{j=1}^{5} e_j^* \ln\left(\frac{HH_t}{HH_0}\right)$$ Number of households effect

$$+\sum_{j=1}^{5} e_j^* \ln\left(\frac{S_{jt}}{S_{j0}}\right)$$ Housing-type effect

$$+\sum_{j=1}^{5} e_j^* \ln\left(\frac{F_{jt}}{F_{j0}}\right)$$ Size effect (square footage per household)

$$+\sum_{j=1}^{5} e_j^* \ln\left(\frac{W_{jt}}{W_{j0}}\right)$$ Weather effect

$$+\sum_{j=1}^{5} e_j^* \ln\left(\frac{I'_{jt}}{I'_{j0}}\right)$$ Intensity effect (energy per square foot)

(1)

Where

E_t = total energy use in year (*t*),

E_0 = total energy use in year (*0*),

j = represents the five types of housing,

[12] U.S. national results are developed in the second stage applying an LMDI-II analysis that combines Census regions. At the U.S. level, the region effect is defined as the difference between the simple growth in the aggregate number of households and the decomposed number of households effect from the 2-stage LMDI-II analysis for combined regions.

HH_t = total number of households,

HH_0 = number of households of housing type j,

S_{jt} = share of housing type *j* in year (*t*)

S_{j0} = share of housing type *j* in year (*0*)

F_{jt} = average floor space of housing type *j* in year (*t*),

F_{j0} = average floor space of housing type *j* in year (*0*),

W_{jt} = weather-adjusted[13] energy consumption of housing type *j* in year (*t*),

W_{j0} = weather-adjusted energy consumption of housing type *j* in year (*0*),

I'_{jt} = weather-adjusted energy intensity of housing type *j* in year (*t*),

I'_{j0} = weather-adjusted energy intensity of housing type *j* in year (*0*),

The final weights (e_j^*) are normalized to sum to one:

$$e_j^* = \frac{e_j}{\sum_j e_j} = \frac{L(e_{j,0}, e_{j,t})}{\sum_{j=1}^{5} L(e_{j,0}, e_{j,t})} \tag{2}$$

and

$$L(e_{j0}, e_{jt}) = \frac{(e_{jt} - e_{j0})}{\ln\left(\frac{e_{jt}}{e_{j0}}\right)} \tag{3}$$

[13] To compute weather adjusted energy consumption, space heating and cooling are degree-day adjusted and added to the other unadjusted end uses, water heating, lighting, and appliances. First heating degree-day (cooling degree day) factors are calculated as the ratio of the average heating degree (cooling degree) days for 1971-2001 to a specified year for each Census region. Then, the amount of each major fuel used for space heating (air-conditioning) is multiplied by the respective heating (cooling) degree-day factor. Finally these weather adjusted estimates are added with the other non-weather sensitive end-use estimates.

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