Energy Efficiency in Multifamily Rental Homes: An Analysis of Residential Energy Consumption Data

Authors Mark Obrinsky and Caitlin Walter

Abstract In this paper, we examine how energy consumption differs among different residential housing types. Most previous research suggests that apartments are less energy efficient than single-family homes, whether owner-occupied or rental. In addition, principal-agent problems in rental housing are said to lead to greater energy consumption by renters. Using microdata from the Residential Energy Consumption Survey, we examined the impact of both structure type and tenure on energy usage. Our results show that multifamily homes are more energy efficient than single-family homes, and that it is not tenure, but rather whether the resident pays for energy directly that affects energy usage.

Energy efficiency in residential real estate matters for at least two reasons. First, energy cost can be a significant contributor to the overall cost of housing, particularly for low- and moderate-income households. Second, as climate change and pollution continue to impact the world in which we live, there has been increased attention on reducing carbon emissions. Much of this has focused on transportation and the efforts to produce more efficient gasoline-based vehicles, as well as to develop and improve vehicles that use alternative fuels. However, real estate is also key to reducing carbon emissions: in 2013, residential and commercial buildings were responsible for 40% of all energy consumption in the United States (Energy Information Administration, 2014a). More than half of that amount was consumed in residential buildings of all types (both owner- and renter-occupied, single-family and multifamily) (Energy Information Administration, 2014b). There were 17.9 million occupied apartments (rented units in buildings with at least five units) in 2013, accounting for approximately one-third of all housing units in the U.S. (United States Census Bureau, 2014).[1]

Many initiatives involve making all buildings more energy efficient. For example, the Obama Administration launched the ''Better Buildings Challenge'' in 2011, which has a goal of reducing energy usage in commercial buildings (which includes multifamily buildings) by 20% or more by 2020 (U.S. Department of Energy, 2014). President Obama has also laid out the goal of doubling the entire country's energy efficiency by 2030 (Plumer, 2013).

Energy usage can vary a great deal across all types of real estate, and even within each type. Residential structures range from single-family detached housing on large lots to multifamily units in high-rise buildings, and each of these structures can be occupied by a renter or a homeowner. Differences in structure and tenure types can lead to differential energy consumption. Other characteristics—climate, age of structure, size of home—can also lead to differences in energy consumption. It is crucial, both for general knowledge and especially for policy aimed at improving energy efficiency, to distinguish among these various influences.

There are two principle ways to measure energy consumption: energy usage per housing unit (or household) and energy usage per square foot. Previous research focusing on improving residential energy efficiency has generally used the latter measure (albeit sometimes implicitly). At first sight, this may have intuitive appeal. However, larger housing units may appear more energy efficient by this measure than smaller ones simply because some energy consumption does not vary with size. Since larger housing units tend to use more total energy than smaller ones, building ever-larger homes could have the perverse effect of lowering energy use per square foot while simultaneously increasing energy use per household and overall energy use.

The second approach is to measure energy consumption per housing unit. This is our preferred measure, because it both starts from the fundamental ''atom'' of residential real estate (the unit, or home, itself) and lends itself to aggregation more easily. Nonetheless, both measures provide insight and our analysis looks at both energy consumption per household (occupied housing unit) and energy usage per square foot.

Our main goal is to analyze two key issues: tenure and housing structure. It is widely argued that renters consume more energy than homeowners because renters who do not pay for their own energy usage have no economic incentive to conserve energy. Alternatively, where renters do pay for their energy usage, property owners have no incentive to make energy-efficient upgrades because savings from lower energy consumption benefits the renter rather than the property owner. In addition, multifamily structures seem likely to use less energy due to their construction style—shared walls would offer some protection and insulation from weather that single-family structures (particularly single-family detached houses) would not. Multifamily rental units may have fewer energy-efficient appliances (due to the agency problem noted above), which may counteract the structural advantage.

Literature Review

The impact of tenure on energy consumption has been widely discussed. In particular, renting has been associated with two principal-agent problems. Where renters do not pay utility bills directly, they have no economic incentive to conserve; hence, renters are likely to use more energy than owners of similar housing units in similar circumstances. Levinson and Niemann (2004) note that tenants may prefer that utilities be included in the rent if they are risk averse (and wish to avoid the chance that utility costs rise more than expected), if they prefer constant monthly payments (since utility costs tend to vary seasonally), or if they simply prefer ‘‘buffet-style’’ pricing (bundling). Their analysis leads them toward landlord-based explanations, however, which involves the second type of agency problem. Maruejols and Young (2011) analyze multifamily buildings in Canada and find that renters who do not pay for utilities directly heat their homes more (that is, set their thermostats higher) than those who pay for utilities directly.

Where renters do pay for utilities directly, landlords (property owners) may have no economic incentive to make investments that increase the energy efficiency of individual housing units, as it is the renter who would reap the benefits (Jaffe and Stavins, 1994; Murtishaw and Sathaye, 2006; Zimring et al., 2011.) There is also a potential principal-agent problem in owner-occupied housing, however. ‘‘If the builder of a new home cannot credibly represent its energy efficiency to potential buyers, then the sale price may not fully reflect efficiency attributes’’ (Jaffe and Stavins, 1994). In this circumstance, the builder has an incentive to make the home less efficient than the homebuyer may want. Davis (2012) concludes that rental units are much less likely to have energy-efficient appliances and lighting. Bird and Hernandéz (2012) note that this split incentive problem can also arise in owner-occupied housing (and commercial real estate), where the split is a temporal one. If owners are going to move soon (or are uncertain when they might move), they are less likely to makes investments to improve energy efficiency if the payback period is long (or unknown).

There is more limited published research currently available concerning the impact of different kinds of residential structures on energy consumption. Pivo (2012, 2014) examined structure and tenure together. He notes that residents in multifamily rentals spend considerably more on energy per square foot than do multifamily owners (i.e., condos and co-ops) or especially single-family owners or renters. He explains this difference in large part by showing that rental units in multifamily buildings have the fewest energy-efficient features (EEFs). He also attributes some of their higher expenditure to the agency problem that arises from renters not paying directly for utilities. Pivo notes as well that some EEFs were less common as household income decreased.

In contrast, Holden and Norland (2004), examining energy use in the Oslo, Norway, metropolitan area, argue that single-family detached housing is the most energy-inefficient type of housing. Brown and Wolfe (2007) note that multifamily homes tend to use less energy than single-family homes, which they attribute to smaller unit size, as well as smaller exterior wall and roof space.

Looking at structure more broadly, Ewing and Fong (2008) suggest that urban form affects residential energy use in three ways: detached houses use more energy than attached houses and multifamily homes; decentralized development increases electrical transmission losses; and urban heat islands increase energy usage for cooling while decreasing energy usage for heating. Energy used for heating tends to dominate energy used for cooling, so that urban heat islands reduce overall energy use. On balance, structure type is more important than the heat island effect. Zimring et al. (2011) found that the costs of making energy-efficient improvements are high enough that it may not be realistic to expect middle-income homeowners in single-family houses to make such investments.

Data and Methods

To address how apartment energy consumption compares to that of other housing types, we used data from the U.S. Energy Information Administration's (EIA) 2009 Residential Energy Consumption Survey (RECS). The RECS is the most comprehensive source available for energy usage in residential structures. The RECS has historically been conducted every four years, but there was no 2013 RECS; hence, the 2009 is the latest RECS.

The survey is based on responses from individual householders. In the case of rental units, if the householder is not sure of all the responses, the property managers, if available, are also contacted. When the householders complete the survey, they also report the name of their utility company. Those companies then submit consumption and billing data for the households to the EIA. For households where incomplete data are available, a model developed by EIA is used to estimate consumption.

The 2009 RECS microdata contain 12,083 records; 541 manufactured homes were excluded from the analysis, resulting in 11,541 records being used for this analysis.[2] Manufactured housing was excluded due to the unique characteristics related to utilities and energy consumption that are common in such housing.

The main goal of this research is to analyze the impact of two things, housing tenure and structure type, on energy consumption. In principle, energy consumption can be measured in three ways: energy usage per household, per household member, and per square foot. Energy use per household member is of little help here: having a baby or taking on a roommate greatly decreases energy usage per person while producing no change (or some increase) in energy usage per household or per square foot.

We are ultimately concerned with total energy consumption in residential real estate. For this purpose, energy use per square foot is not ideal: the larger the unit, the less intensively the space may be used, hence the lower the energy use per square foot even though the total energy used in the housing unit is greater. Put differently, adding space to a housing unit without increasing the number of energy-using appliances (such as dishwashers and refrigerators) would likely reduce energy consumption per square foot, but increase total energy consumption. It is the latter that is of interest here. Hence, energy consumption per household is the most useful metric. Nonetheless, we analyze energy consumption per square foot as well as per household.

Top-level findings are published by the RECS but as the following exhibits show, those results are helpful but insufficient.

As one might expect, single-family detached homes in the dataset use the most energy per household, followed by single-family attached and units in buildings with between two and four units.[3] Units in large multifamily buildings use the least total energy by far. In contrast, energy usage per square foot is lowest in single-family homes, somewhat higher in large building multifamily units, and highest in small building multifamily homes (Exhibit 1).

Exhibit 1 | Energy Usage by Housing Type

Housing Type	BTUs per Household (millions)	BTUs per Square Foot (000s)
Single-family detached	105.7	42.6
Single-family attached	81.3	46.0
2–4 units in building	76.1	69.2
5 or more units in building	46.3	54.5

Note: The top-level tables from EIA include the outlier response as well as manufactured housing. The source is the Energy Information Agency, 2009 Residential Energy Consumption Survey.

Exhibit 2 | Number of Housing Units by Structure Type and Division

Division	Single-Family Detached	Single-Family Attached	Homes in 2–4 Unit Buildings	Homes in 5+ Unit Buildings	Total
New England	535	67	160	159	921
Middle Atlantic	654	154	172	316	1,296
East North Central	841	59	78	145	1,123
West North Central	1,264	106	75	181	1,626
South Atlantic	1,452	161	120	349	2,082
East South Central	460	26	30	58	574
West South Central	820	73	79	202	1,174
Mountain North	303	55	20	48	426
Mountain South	243	20	13	52	328
Pacific	1,230	169	179	413	1,991
Total	7,802	890	926	1,923	11,541

Note: The source is the Energy Information Agency, 2009 Residential Energy Consumption Survey.

Exhibit 2 shows that small building multifamily homes are concentrated heavily in New England and the Middle Atlantic: these two divisions have 15% of all housing units, but 36% of all small building multifamily homes. Cold winters rather than any structure characteristics probably explain the energy use disparity. The share of single-family detached homes is highest in the East North Central, West North Central, and East South Central divisions. The highest concentration of large building multifamily homes is in the Middle Atlantic and Pacific divisions. The very different climates in these areas are likely to affect meaningfully the energy usage.

Similarly, the energy consumption by tenure indicates owners use more energy per household whether in single-family or multifamily structures (Exhibit 3). But

Exhibit 3 | Energy Usage by Housing Type and Tenure

Housing Type	BTUs per Household (millions)	BTUs Per Square Foot (000s)
Single-Family Owned	106.5	41.8
Single-Family Rented	86.6	51.6
Multifamily Owned (2+ units)	74.2	57.2
Multifamily Rented (2+ units)	53.0	60.7

Note: The source is the Energy Information Agency, 2009 Residential Energy Consumption Survey.

Exhibit 4 | Energy Usage by Age of Building

Year Built	BTUs per Household (millions)	BTUs per Square Foot (000s)
Before 1940	110.1	51.6
1940 to 1949	96.7	52.0
1950 to 1959	97.1	52.5
1960 to 1969	87.9	50.2
1970 to 1979	79.0	46.9
1980 to 1989	77.0	43.5
1990 to 1999	87.8	39.9
2000 to 2009	91.5	37.1

Note: The source is the Energy Information Agency, 2009 Residential Energy Consumption Survey.

the relation is reversed when looking at energy consumption per square foot. Again, however, the range in energy usage per square foot is much smaller than energy usage per household.

Exhibit 4 shows a higher usage per household in the oldest homes (those built before 1959). For units built in 1960 to 1989, usage gradually decreases. After that point, usage begins to increase for newer homes. By contrast, energy usage per square foot declines as units get newer. This is perhaps due to the increasing size of homes after 1989, which could increase total energy consumption per household, but not per square foot. More energy-efficient building design or appliances may explain the continued decrease in energy usage per square foot, although this might not have offset increasing size.

Exhibit 5 shows energy consumption by end use. Heating represents the largest end use, taking over five times more energy than cooling (air conditioning). Combined, heating and cooling of space make up 51% of the nation's residential

Exhibit 5 | Energy Consumption by End Use

	Energy Usage per Household (million BTUs)	Share
Space Heating	38.7	43%
Air Conditioning	6.8	8%
Water Heating	16.0	18%
Refrigerators	4.3	5%
Other	26.7	30%
Total	89.6	100%

Note: The source is the Energy Information Agency, 2009 Residential Energy Consumption Survey.

energy consumption. In addition to water heating and refrigerators, other main uses involve lighting, clothes washers and dryers, cooking appliances, televisions, dishwashers, computers, pools, and hot tubs.

Many other factors are likely to affect energy consumption as well. To isolate the effect of tenure and structure type on energy use, the use of regression analysis is necessary to hold constant all other variables that may come into play. We employed ordinary least squares (OLS) regression. While space heating and cooling depend to an important degree on the size of the unit (the amount of space to be heated), most of the other uses are likely to be affected much less by unit size. (For example, a house twice as big as a neighboring house is unlikely to have twice as many refrigerators or use twice as much energy for water heating.) For this reason, in addition to analyzing total energy use (per household and per square foot), we also analyzed space heating and cooling as separate equations to understand whether housing structure or tenure had a different impact on these uses.

Over 900 variables were available in the RECS microdata; for this analysis, 11 variables were included (Exhibit 6). Due to the large variation in the characteristics of housing units, as well as the households that occupy them, many control variables were included. In multiple cases, the larger categorical variable was divided into multiple dummy variables in order to produce more meaningful coefficients.

Dependent Variables

Both energy consumption and energy expenditure data are available in the RECS microdata. We chose to use energy consumption, as our interest is in the amount of energy used rather than its cost. (Energy expenditures likely would be preferred if the focus were on, for example, affordability.) Although RECS provides energy consumption data in both British Thermal Units (BTUs) and kilowatt hours (kWh), we follow most academic research and federal energy-efficiency programs in using

Exhibit 6 | Summary Statistics

Variable	Min.	Max.	Mean
Division	1	10	5.35
Type of housing unit	1	4	1.74
Heating degree days in 2009, base temperature 65°F	0	12,525	4,160
Cooling degree days in 2009, base temperature 65°F	0	5,480	1,402
Housing unit is rented (tenure)	0	1	0.33
Age of housing unit	0	89	38.56
Household member at home on typical week days	0	1	0.56
Number of persons in household	1	2.66	14
2009 gross household income	1	5	2.70
Household pays for utilities	1	3	1.11
Log of unit size in square feet (includes heated / cooled garages, all basements, and finished / heated / cooled attics)	4.61	9.65	7.44
Total usage (in thousand BTU) 2009	58	604,612	90,882
Total usage for space heating (in thousand BTU) 2009	0	548,711	37,505
Total usage for air conditioning (in thousand BTU) 2009	0	95,712	5,741

Note: The source is the Energy Information Agency, 2009 Residential Energy Consumption Survey. The number of observations is 11,541.

BTUs as the unit of measurement. In addition to estimating energy consumption per household, we estimate energy consumption per square foot, an alternative way to gauge efficiency.

As noted above, energy used for heating and cooling makes up only half of total energy usage. We also hypothesized that heating and cooling depend on unit size to a far greater extent than other uses. For that reason, we separately analyzed energy usage for space heating and for space cooling; that is, we estimated equations using heating and separately cooling, as dependent variables.

Independent / Control Variables

Division. The RECS provides high-level geographic information. Each observation is associated with one of the four standard Census regions, as well as one of ten divisions: New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain North, Mountain South, and Pacific. These are the same as the standard Census nine division definitions, except that the Mountain division has been split into two, north and south. In addition to widely varying climate conditions, hopefully captured in other variables, divisions may have differences in type of heating equipment, presence of air conditioning, presence of attics, basements, and garages that could affect energy usage. Including divisions also allowed for possible differences of tradition or culture. For example, it may be that New Englanders use less air conditioning than those in the South Atlantic, even for the same outside temperature.[4]

Tenure (Renting vs. Owning). To account for the possibility that there are other aspects of tenure that could affect energy use, tenure is included as an explanatory variable. There are three tenure categories in RECS: owned, rented, and ''occupied without the payment of rent.'' Sample size constraints led us to combine the latter two into one category, creating a dichotomous variable.

Household Pays for Its Own Utilities. As noted in the discussion of principal-agent problems above, the critical issue is not tenure per se, but rather whether renters pay directly for energy use. In addition to tenure, the RECS microdata contain information on which, if any, utility bills a household is responsible for. For simplicity, we separate households who pay at least one utility bill (other than water) from households that have all utilities included in their rent. There is also a category for households that have at least one utility bill paid in some other manner (typically by a government program).

Type of Housing Unit. The physical characteristics of different housing unit types likely affects energy consumption; in particular, multifamily homes are likely to use less energy. We use four response categories for this variable: single-family detached, single-family attached, homes in buildings with 2–4 units, and homes in buildings with 5 or more units.

Number of Heating Degree Days and Number of Cooling Degree Days. Heating (or cooling) degree days are defined as the number of days and degrees above (or below) 65°F. For example, one day at 32°F would result in 33 heating degree days while one day at 98°F would result in 33 cooling days. In theory, for both variables, the higher the number of days and greater the amount of temperature variation, the larger the amount of energy consumed.

Age of Housing Unit. The microdata include the year of construction of the housing unit. This was subtracted from the year the survey was collected, 2009, to get the age of the housing unit. Older housing units may be less energy efficient because newer housing units are more likely to feature energy-saving design and construction. In addition, heating and cooling equipment may become less efficient over time, and wear and tear could also impair the home's energy efficiency. While repairs and alterations likely offset those effects to some extent, the age of the housing unit should still much of this difference.

Log of Unit Size. Since total energy usage includes energy used for heating and cooling, larger housing units should generally have higher energy usage. It is less clear whether or how unit size should affect energy consumption per square foot. Aggregate data from the RECS survey show the smaller the housing unit, the more energy consumed per square foot. This could be because larger homes have correspondingly higher energy consumption for heating and cooling, but not for appliances and other purposes. The log of the size of each unit was included because the relationship between energy consumption and size was not expected to be linear. In particular, it was expected that energy needs increase with size, but at a diminishing rate.

Household Income. Energy billing comprises a larger portion of low-income households' budgets; as a result, they may be more likely to conserve energy (where possible). Conversely, owner households with higher incomes are more likely to be able to afford to make energy efficiency upgrades, which may lower energy consumption. We divided household income into five categories.[5]

Household Member Home on Typical Weekdays. Whether or not there is a household member at home during the day was included as a control variable, as this is likely to affect energy usage.

Number of Household Members. While doubling the number or persons in a housing unit is not likely to double energy consumption, it is likely to increase energy use somewhat.

Results and Discussion

An OLS analysis was run based on the following hypotheses:

Hypothesis 1: Households that pay for their energy use directly consume less energy than those households that do not pay directly. Although direct payment for energy is somewhat correlated with tenure, tenure itself does not affect energy use.

Hypothesis 2: Multifamily housing units consume less energy than other lower-density housing types.

These two hypotheses were tested on both total energy usage per household and total energy usage per square foot. In addition, we analyzed the related issue of impact of structure on energy consumption solely for space heating, and separately space cooling.

The results are shown in Exhibits 7 and 8. We used the same explanatory variables in all four equations except that cooling degree days were omitted from the equation for heating, while heating degree days were omitted from the equation for cooling. In addition, there were 2,053 observations in which the amount of energy used to cool the home was zero; these were also omitted from the equation for cooling. The results strongly support our hypotheses. In both equations for total energy use—per household and per square foot—most variables were significant and had the expected signs.

The renter dummy variable was not significant in the equation for total energy consumption per household, as expected. It was significant when estimating energy use per square foot, but with a negative sign, indicating that renters actually use less energy than owners. This result was robust for alternative specifications of the equation. We can offer no theoretical basis for this result, but instead view it as a likely artifact of the data set.

Also as hypothesized, whether or not the household was directly responsible for at least part of the utility payment was statistically significant in both equations. In both cases, paying energy costs indirectly through rent (*Utilities_2*) led to

Exhibit 7 | Regressions Results for Total Energy Consumed

	Energy Use per Household			Energy Use per Square Foot		
	Coeff.	Robust SE	Significance	Coeff.	Robust SE	Significance
Renter	−1285.1	1088.054	0.238	−3.18	0.890	0.000
Utilities_2	8137.5	1171.042	0.000	19.36	1.639	0.000
Utilities_3	31617.8	5818.432	0.000	27.32	6.719	0.000
Structure_2	−11244.1	1306.131	0.000	−8.24	0.909	0.000
Structure_3	−5852.0	1692.002	0.001	−7.51	1.804	0.000
Structure_4	−16998.4	1263.134	0.000	−23.70	1.151	0.000
Log of area	33328.4	1110.751	0.000	−37.10	1.315	0.000
Unit age	213.3	17.625	0.000	0.14	0.012	0.000
HDD	4.46	0.598	0.000	0.002	0.0003	0.000
CDD	−0.38	0.836	0.646	−0.002	0.005	0.001
# persons	4865.0	271.041	0.000	2.90	0.163	0.000
At home	5857.9	747.454	0.000	4.02	0.552	0.000
Income_2	−512.4	925.518	0.580	−0.71	0.817	0.383
Income_3	453.4	1085.608	0.676	0.37	0.806	0.645
Income_4	5903.9	1377.880	0.000	3.91	0.891	0.000
Income_5	19504.0	1390.578	0.000	9.34	0.902	0.000
Mid Atl	3815.4	2041.557	0.062	3.36	1.375	0.014
E N Central	2674.8	2099.770	0.203	3.12	1.933	0.107
W N Central	−4337.6	1953.730	0.026	−3.26	1.201	0.007
S Atl	−12287.7	2286.276	0.000	−7.40	1.384	0.000
E S Central	−8536.1	2450.748	0.000	−6.17	1.613	0.000
W S Central	−1278.3	2344.245	0.586	−2.01	1.453	0.167
Mountain N	−2588.6	2635.045	0.326	−3.07	1.561	0.049
Mountain S	−5657.0	2819.673	0.045	−2.39	1.701	0.161
Pacific	−16928.4	2775.840	0.000	−15.11	1.646	0.000
Constant	−194119.3	9499.052	0.000	312.75	10.364	0.000

Notes: The number of observations is 11,541. For energy use per household, $F(25,11515) = 408.55$, Prob $> F = 0.0000$, and adj. $R^2 = 0.475$. For energy use per square foot, $F(25,11515) = 106.17$, Prob $> F = 0.0000$, and adj. $R^2 = 0.365$.

Renter is a dummy variable equal to 1 for renters and 0 for owners.

Utilities_2 is a dummy variable equal to 1 when utilities are included in the rent; *Utilities_3* is a dummy variable equal to 1 when utilities are paid by an outside entity. For renters who pay indirectly for utilities in their rent, both these dummy variables equal 0.

Structure_2 is a dummy variable equal to 1 for single-family attached homes; *Structure_3* is a dummy variable equal to 1 for homes in buildings with 2–4 units; *Structure_4* is a dummy variable equal to 1 for homes in buildings with 5+ units. For single-family detached homes, these three dummy variables all equal 0.

HDD = heating degree days

CDD = cooling degree days

Income_2 = \$25,000–\$49,999; *Income_3* = \$50,000–\$74,999; *Income_4* = \$75,000–\$99,999; *Income_5* = \$100,000 or over. For those with incomes of less than \$25,000, these four dummy variables equal 0.

Exhibit 8 | Regressions Results for Energy Consumed for Heating and Cooling

	Energy Use per Household: Heating			Energy Use per Household: Cooling		
	Coeff.	Robust SE	Significance	Coeff.	Robust SE	Significance
Renter	−160.1	719.736	0.823	−138.9	152.445	0.362
Utilities_2	2240.6	790.483	0.005	3077.7	193.790	0.000
Utilities_3	2742.3	2670.087	0.304	4454.7	955.042	0.000
Structure_2	−3307.4	856.70	0.000	−838.4	165.921	0.000
Structure_3	−1066.3	1116.399	0.340	−130.0	218.574	0.552
Structure_4	−6861.0	840.438	0.000	−426.0	205.329	0.038
Log of area	14890.8	688.44	0.000	−5410.2	207.691	0.000
Unit age	235.8	12.289	0.000	−17.1	2.333	0.000
HDD	5.669	0.240	0.000			
CDD				4.4	0.130	0.000
# persons	−933.7	165.965	0.000	68.9	43.603	0.114
At home	2236.6	501.569	0.000	589.2	120.557	0.000
Income_2	−755.8	655.824	0.249	254.6	141.917	0.073
Income_3	−1705.2	749.327	0.023	757.2	162.093	0.000
Income_4	718.2	949.091	0.449	1102.2	200.622	0.000
Income_5	5317.7	929.782	0.000	2537.0	223.416	0.000
Mid Atl	−1963.2	1513.718	0.195	526.4	172.991	0.002
E N Central	−5500.6	1581.140	0.001	736.4	176.166	0.000
W N Central	−12777.2	1504.160	0.000	1439.8	179.950	0.000
S Atl	−18327.7	1697.556	0.000	2913.0	269.447	0.000
E S Central	−17872.3	1736.974	0.000	4052.3	293.378	0.000
W S Central	−14811.1	1710.692	0.000	4061.6	372.356	0.000
Mountain N	−8000.1	1841.698	0.000	884.5	243.676	0.000
Mountain S	−15844.7	1913.158	0.000	2508.9	666.459	0.000
Pacific	−17055.1	1718.406	0.000	316.0	232.296	0.174
Constant	−91964.3	5505.491	0.000	−42920.1	1631.372	0.000

Notes: The number of observations is 11,541. For energy use per household: heating, F(24,11516) = 354.64, Prob > F = 0.0000, and adj. R^2 = 0.470. For energy use per square foot: cooling, F(24,9463) = 276.74, Prob > F = 0.0000, and adj. R^2 = 0.574.

Renter is a dummy variable equal to 1 for renters and 0 for owners.

Utilities_2 is a dummy variable equal to 1 when utilities are included in the rent; *Utilities_3* is a dummy variable equal to 1 when utilities are paid by an outside entity. For renters who pay indirectly for utilities in their rent, both these dummy variables equal 0.

Structure_2 is a dummy variable equal to 1 for single-family attached homes; *Structure_3* is a dummy variable equal to 1 for homes in buildings with 2–4 units; *Structure_4* is a dummy variable equal to 1 for homes in buildings with 5+ units. For single-family detached homes, these three dummy variables all equal 0.

HDD = heating degree days

CDD = cooling degree days

Income_2 = \$25,000–\$49,999; *Income_3* = \$50,000–\$74,999; *Income_4* = \$75,000–\$99,999; *Income_5* = \$100,000 or over. For those with incomes of less than \$25,000, these four dummy variables equal 0.

increased energy consumption. Having an outside entity (generally government) pay for energy costs (*Utilities_3*) also resulted in increased energy usage. The coefficient was surprisingly large: almost four times as large as the coefficient for those paying for energy costs in the rent bill. The number of such occurrences is small, however, comprising less than 1% of the observations.

Both regressions showed that homes in large multifamily buildings used the least energy. Single-family attached houses and homes in small multifamily buildings used less energy than single-family detached homes, but more than homes in large multifamily buildings. The coefficient for homes in small multifamily buildings was greater (indicating more energy consumption) than the coefficient for single-family attached houses. The 95% confidence intervals for the two coefficients overlapped in both equations, however, indicating we cannot be confident that energy use was actually less in single-family attached houses. Since single-family attached houses and homes in small multifamily buildings are relatively similar structurally, this result is understandable.

The size of the housing unit was significant in both regressions. We tested alternative size specifications; the log of the area provided the best fit and matched our expectation for nonlinearity. For energy consumption per household, energy usage increased with unit size, as expected. For energy consumption per square foot, energy usage declined with unit size, also as expected. This latter result also suggests caution in using energy consumption per square foot as a measure of energy efficiency.

The age of the housing unit was statistically significant in the regressions and with the expected sign: older homes used more energy than newer homes. In addition, the number of heating degree days was significant in both equations and with the expected sign: more heating degree days resulted in greater energy consumption. However, the number of cooling degree days was not significant for the energy consumption per household. It was significant for energy consumption per square foot, but with a negative sign: a larger number of cooling degree days resulted in less energy consumption. Both results are contrary to expectations.

The number of persons in the household was significant and in the expected direction: more persons per household led to greater energy usage per household and per square foot. In addition, the variable for household member home during most weekdays was significant and had the expected sign. That is, if a member of the household was home most weekdays, energy consumption increased, both per household and per square foot.

Household income was significant in both equations, but only for some incomes. For incomes of $25,000–$49,999 and $50,000–$74,999 (*Income_2* and *Income_3*), energy consumption was not significantly different from households with an income of $0–$24,999. Above the $75,000 level (*Income_4* and *Income_5*), income was significant and in the expected direction: higher income increased energy consumption.

The results were mixed regarding the impact of geography. The coefficients for most, but not all, divisions were significant, indicating energy use in those regions was significantly different from that of New England. The lowest energy consumption per household was found in the Pacific division, followed by the South Atlantic and East South Central divisions. The lowest energy consumption per square foot was in the Pacific division, followed by the East South Central and West South Central divisions. These results are consistent with the overall data showing that households use more energy for heating than for cooling.

The results of these two estimations regarding both cooling degree days and geographic divisions suggest estimating energy consumption for space heating and cooling separately, as the need for heating or cooling a home differ depending upon climate and geography and the interaction may be affecting the estimation of total energy consumption.

As noted above, heating and cooling together make up only half of total energy consumption. Consequently, these next regressions intentionally do not cover all energy usage, but only that which stems from household climate control.

These results further support our hypotheses.[6] Tenure as such is not significant for either space heating or cooling, but whether the renter pays for energy directly is significant.[7] In these regressions, the coefficients for *Utilities_3* (energy costs are paid by neither the resident nor the property owner, if different, but rather by an external entity) are quite similar to the coefficients for *Utilities_2* (utilities are paid implicitly through rent), a more understandable result than in the equations for total energy use.

Large building multifamily homes used less energy for heating than homes in other structure types. They also used less energy for cooling than did single-family detached homes. The coefficients for small building multifamily units were not significant, either for heating or cooling, but once again the 95% confidence intervals overlap with the confidence intervals for the coefficients on single-family attached homes. It seems reasonable to regard energy use for heating and cooling in single-family attached homes and small building multifamily units as similar. Single-family attached homes seemed to use the least energy for cooling of all structure types. The reason for this result is unclear.[8]

Heating degree days, cooling degree days, and whether someone was at home during weekdays were all significant with the expected signs and reasonable coefficients. In the space heating regression, the log of unit size was significant with the expected sign. The number of persons in the household also appeared to be significant, although with a negative sign. With the exception of the Middle Atlantic, all divisions were significant and used less energy for heating than New England. Two of the four income category coefficients were significant, with the highest income group using significantly more energy for heating than all other income groups.

In the space cooling regression, the number of persons was not significant. Unit size and age were significant, but with unexpected negative signs. The sign for age may be capturing the fact that many older homes have only room air conditioners for some rooms rather than central air conditioning, hence are cooling only a portion of the home.[9] Incomes of $50,000 and above were significant and in the expected direction, with higher incomes leading to greater energy use for cooling throughout. All divisions but the Pacific (whose coefficient was not significant) used more energy for cooling than New England, and the East South Central and West South Central divisions used the most.

Conclusion

The regression results strongly support the hypothesis that large building multifamily homes use less energy than other housing structures. The relation is statistically significant for total energy usage, both per household and per square foot. The latter is an especially strong result. Along with our finding that larger units use more energy per household, but less energy per square foot, this confirms that it is not their smaller average size, but their overall structure, that makes large building multifamily units more efficient than single-family homes. The energy saved by large building multifamily units is also of significant magnitude. The coefficient for such units in the regression for total energy usage indicates that the mean energy usage is 16,998 BTUs less than that for single-family detached homes, or 18.7% of the mean total energy usage of 90,882 BTUs.

The results also support the hypothesis that tenure does not play a role in energy usage. Instead, what matters is whether the household pays its own utilities. When stated in this fashion, it may not be surprising, but it is a distinction worth making. In addition to providing analytical clarity, this difference may have useful policy implications. For example, retrofitting apartments to allow for submetering of residents should lead to a reduction in energy use.

The magnitude of this factor is rather large. For total energy usage, householders who pay for utilities use an average of 8,138 BTUs (9.0% of the total) less than householders who do not. For heating, the energy usage is 2,241 BTUs less (6.0% of the mean energy used for heating); for cooling, the energy consumption is 3,078 BTUs less (53.6% of the mean energy used for cooling).

The results on the impact of whether households pay for utilities provide strong support to the first of the two principal-agent problems outlined above: when renters do not pay directly for energy, hence have no economic incentive to conserve, they are likely to use more energy.

Our analysis goes a long way toward explaining the greater energy usage per square foot in apartments. The regression results showed that increasing size led to decreasing energy usage per square foot (that is, the coefficient on unit size was negative). This turns out to be true for heating, cooling, and other energy usage as well. Since apartments are smaller than other types of housing, this raises energy usage per square foot.

The second factor is the fact that many apartment residents do not pay for utilities directly; instead, utility costs are included in rent. As noted above, this skews apartment energy usage upward by a large amount.

Beyond that, some of the disparity in energy usage by housing type may stem from the fact that apartment homes have less efficient appliances and other energy-efficient features (Pivo, 2014). This explanation may need refinement, however, as apartments use more energy per square foot for space heating than other types of housing, but use less energy per square foot for space cooling than single-family homes, whether renter- or owner-occupied.

Our analysis shows that the RECS microdata are a valuable source for examining the key determinants of energy usage. This is of importance not only for enhancing our understanding of this increasingly important area, but also potentially for implementing strategies to reduce overall energy consumption. The fact that billing residents separately for energy utilities reduces energy usage confirms that retrofitting apartments to submeter residents separately could contribute meaningfully to reducing energy consumption. To be sure, this then leads to the other principal-agent problem noted above: when residents pay directly for utilities, investments in energy efficiency are unlikely to accrue to the property owners who incur the expense of the retrofit. More broadly, greater reliance on multifamily buildings to meet the continuing increase in housing demand would seem to have clear benefits in reducing energy consumption.

Our results lend themselves to further investigation in a number of areas. We expected that higher incomes would lead to greater energy usage beginning at a lower income level than our analysis showed; additional insight here would be welcome. This work could also be extended by including data on type (and efficiency) of heating and cooling equipment, which might help explain the anomalous results for cooling degree days in our estimates for total energy consumption. There also may be some interaction of division, cooling degree days, and cooling equipment that could lead to a better understanding of the impact of cooling degree days on total energy use.

Another RECS is planned for 2015. We look forward to re-estimating these equations with the 2015 data to test the robustness of our findings over time.

Endnotes

[1] Throughout this paper the term ‘‘apartments’’ refers to rental units in buildings with at least five units. Owners-occupied units in multifamily buildings are occasionally referred to here as ‘‘condos and co-ops.’’ While both condos and co-ops refer to a legal arrangement rather than a building structure, in fact almost all condos and co-ops are multifamily. ‘‘Large building multifamily units’’ refers to all units (whether owned or rented) in buildings with at least five units. Separately, ‘‘units’’ and ‘‘homes’’ are used interchangeably.

[2] Also excluded was one outlier that had total BTU consumption almost twice the consumption amount of the next-highest response.

[3] Throughout this paper ‘‘small multifamily buildings’’ refers to buildings with between two and four units. ‘‘Small building multifamily homes’’ refers to units in such buildings. ‘‘Small multifamily rentals’’ similarly refers not to the size of the unit, but the rental units in buildings with between two and four units.

[4] When using dummy (or dichotomous) variables to handle categorical data in regression analysis, one of the categories must be excluded. Otherwise, there is perfect collinearity

among the dummy variables and the regression equation cannot be estimated. For example, there are nine Census divisions. Our regression equation includes dummy variables for eight divisions; the New England division was excluded. Thus, the coefficients on each division indicate how energy consumption in that division differs from New England. Each regression results table indicates which category was excluded.

5 Using narrower income categories has no discernible effect on the significance of the income variable.

6 We also estimated energy consumption per square foot for space heating and cooling. As no additional surprises appeared, we omit these equations for simplicity. Some comments are included where these results differed from the results for the equations for space heating and cooling energy consumption per household.

7 In the regression for energy used for heating per square foot, tenure appeared to be significant, but with the wrong (negative) sign for renting. Again, we can think of no reason why renters might use less energy per square foot for heating their homes that is not already captured by other variables.

8 Note that this did not hold up for cooling per square foot, where single-family attached homes used less energy than single-family attached but more than homes in small multifamily buildings. In turn, homes in small multifamily buildings used less energy for cooling that did homes in large multifamily buildings.

9 In the regression for cooling per square foot, age was not significant. Unit size was significant, but here the negative sign was expected, as noted in the discussion of the results for total energy use per square foot.

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Mark Obrinsky, National Multifamily Housing Council, Washington, DC 20036 or mobrinsky@nmhc.org.

Caitlin Walter, National Multifamily Housing Council, Washington, DC 20036 or cwalter@nmhc.org.