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Article

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A zip code study of socioeconomic, demographic, and household gendered influence on the residential energy sector



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HIGHLIGHTS

- Influence of socio-demographics on household energy utilization is evident.
- Gender influence is significant in understanding residential energy consumption.
- Energy consumption increases significantly around the median age of 40–55.
- Owner occupied single-family dwellings use more total energy than renter units.
- Predictive analyses of social variables for good energy policy are prescribed.

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ABSTRACT

This study investigates the influence of socioeconomic and demographic characteristics of the population on residential energy utilization patterns at the ZIP code level in San Antonio, Bexar County, Texas. The City of San Antonio, Texas is the seventh most populous city in the United States and second in the State. Variables analyzed include gender, median age, median income, educational attainment, occupancy, population density, total energy, per capita energy and per home energy. Statistically significant relationships between variables are discovered and highlighted in support of public policy development to ensure long-term, and cost-effective energy management.

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1. Introduction

With the influx of smart energy systems, intelligent appliances, connected devices, sensors and meters, now more than ever the influence of socio-demographic and gendered energy utilization is manifested. For the most part, human social behavior and the role it plays in household energy consumption has been largely overlooked in past energy research despite the fact that behavior significantly dampens and amplifies the effects of technology-based efficiency measures (Lutzenhiser, 1993). Behavior is often driven by the socio-economic and geographical culture and can directly influence energy consumption and conservation. Understanding important determinants of residential energy

consumption is key to the design and implementation of energy conservative policies that pursue sustainability (Brounen et al., 2012).

Over the next two decades the US Department of Energy's Energy Information Administration estimates that US energy consumption will increase by about 40% (Wiggins et al., 2009). Households contribute approximately 15%–20% of the total energy consumption in the United States. Within a household there are many factors that influence energy conservation ranging from socio-demographic to behavioral practices (Steg, 2008). In addition to their growing size and significant contribution to national energy consumption and green house gas production, residential households represent an important target group for energy conservation. Abrahamse and Steg (2009) note that household energy is significantly related to socio-demographic variables. For example, in San Antonio, it is found that households with higher incomes living in larger homes tend to use more energy even though they are more efficient in a per square foot basis due to their newer and better building envelope (see Elnakat et al., 2015 and Gomez et al., 2014).

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Beyond academic curiosity, the results of the marriage of demographic and socioeconomic data with housing characteristics and energy consumption data have practical demand side management applications for electric utilities, city planning officials and the public at large. Such energy analytics can provide a more targeted approach to developing energy efficiency and conservation programs, utility rebate programs, comparative billing, and a more customer-centric and eco-centric approach for optimizing residential energy consumption.

2. Background

2.1. The city of San Antonio: A microcosm for the future US populous

Texas is one of the fastest growing states in the nation with three of its major cities on the Top-10 list of most populous cities in the country (US Census Bureau, 2010). San Antonio is the second largest city in Texas and a dominant city in the south Texas and Mexico border region and a modern metropolis home to approximately 1.3 million people in 2010 (US Census Bureau, 2015). While the national population growth rate is 9%, San Antonio is growing much faster at a rate of 16% per year. As the city continues to grow as a melting pot of heritage, history, and employment opportunities, the city represents a growing economy and can be seen as a microcosm of America's future with regards to demographic and economic diversity and the many infrastructure challenges faced by rapidly growing communities. The importance of highlighting the area's rich heritage is to emphasize the influence of the city's history on socio-demographics transcending to education, income, and as consequence, the built environment, and resulting energy utilization patterns.

2.2. Energy and demographics

Energy efficiency is influenced by many important factors including vintage of home, size of home, socio-economic, demographics, and composition of household family. Many of these factors, to include building stock, can be linked back to neighborhood characteristics unique to that area of town. Lower income neighborhoods will typically have older and smaller homes that are normally less efficient as evidenced by their higher electric intensity and higher energy use intensity, energy utilized per square foot of conditioned space. Bingham and Zhang (2001) equate Zone Improvement Plan (ZIP) codes to central-city neighborhoods in Ohio and studied the effects of neighborhood characteristics, business location, and neighborhood health. "Economically disadvantaged neighborhoods in the US often have a large fraction of minority and female headed households" (Arora and Cason, 1999). Elnakat and Gomez (2015) highlight the role that women's participation in energy can have on residential energy intensity. Study conclusions show that female dominant households have approximately 80% higher per capita energy consumption driven by around double the gas consumption and about 54% more electric usage. Lower income neighborhoods are likely to have higher energy consumption per square foot of living space due to older less efficient homes combined with a higher percentage of female dominant households, both of which have been statistically shown to have a higher energy use intensity.

Furthermore, women and residents that spend a majority of their time at home (such as retirees and the elderly) tend to use more water for personal hygiene and cooking and therefore tend to use more energy required for water heating (Domene and Sauri, 2006). In another example, there is a tendency for electric consumption to be higher during the stage of life when children have moved out and residents are over 55 years old than in the

stages where children and teenagers still live at home. The elderly tend to use less energy on washing/drying clothes and washing dishes but more energy on lighting and conditioning their space compared to younger citizens (Gram-Hanssen et al., 2004).

The occupancy hypothesis explains that renter-occupied buildings contain fewer energy efficiency investments than owner-occupied buildings. The renter will not invest in energy efficiency fixtures for a rented unit due to the inability to fully capitalize on the value of the investment. Reversely, the owner will not invest in energy efficiency since the renter pays the electric bill and therefore the owner has no incentive (Sutherland, 1991). However, data has shown that size of home is a significant variable and most renter-occupied buildings tend to be smaller, this could lead to a trend of more energy consumption in the owner-occupied larger homes as presented in the results section of this study. As square footage increases so does the need for heating and cooling, additional lighting, and the likelihood of extra appliances (The News, 2012). In San Antonio newer homes with larger square footage tend to have a lower energy intensity due to the presence of more efficient heating and cooling systems, better building envelopes and improved overall efficiency but a higher total energy consumption per home when compared to smaller, older homes (Elnakat et al., 2015; Gomez et al., 2014).

Tenants residing in apartments that advertise utilities included with rent tend to use more energy than tenants who pay a separate energy bill. It is estimated that utility included apartments comprise 30% of rented apartments in the US (Levinson and Niemann, 2004). The Residential Energy Consumption Survey conducted by the US Energy Information Administration in 2009 estimates that approximately 31.5% of housing units in the US are renter-occupied. Low-income households tend to rent their homes, which can be characterized as low-income, small rental units. High density living doubled up with relatives or friends, voluntarily or involuntarily, is a common strategy for people to afford a rental unit (Skobba et al., 2013).

2.3. ZIP Codes

The US Postal Service created ZIP codes as a way to classify street segments, address ranges, and delivery points to expedite the delivery of mail. Since US Postal Service ZIP codes are not technically geographical areas, but rather a collection of mailing routes, ZIP Code Tabulation Areas (ZCTAs) – which are generalized area representations of ZIP code service routes – are created by the US Census Bureau to segment data. These ZCTAs are what the Census Bureau uses to segment their socioeconomic and demographic data and thereby what this study uses to correlate household and housing characteristics with energy consumption.

The use of ZIP codes for purposes outside of delivering mail is quickly becoming commonplace. As of 2005, around 193 articles are indexed by "ZIP code" in the Social Sciences Citation Index, and 386 are indexed in PubMed. Since ZIP codes are usually seen in a geographic context, they are utilized in socioeconomic planning, epidemiology, and retailing. For example, retail stores request ZIP codes from their customers after purchases in order to identify the geographical extent of the store's trade area. In epidemiologic research, ZIP codes are used to categorize access to health care (Fourtney et al., 2000), map prostate cancer (Johnson, 2004), track unmarried teen births (Blake and Bentov, 2001), and establish local/regional differences in radon levels (Steck et al., 1996; Grubestic, 2008). Researchers should be diligent in their awareness that ZIP codes are created by the US Postal Service to expedite mail delivery and account for the variations when comparing ZIP codes or ZCTAs (Misra et al., 2014).

Table 1
Segmentation brackets for variables of interest.

Variable	Low	Medium	High
Median age	<30 years	30–40 years	>40 years
Median income	<\$30,000	\$30,000–\$45,000	>\$45,000
Educational attainment – high school (HS) or less	<41.0%	41.0%–63.0%	>63.0%
Educational attainment – bachelor's or higher	<21.5%	21.5%–37.5%	>37.5%
Male to Female ratio	<0.95	0.95–1.05	>1.05
Owner to Renter ratio	<0.95	0.95–1.05	>1.05
Population density	<2.5	2.50–3.00	>3.00
% Single-family detached homes	<40%	40%–60%	>60%

3. Methodology

Socioeconomic and demographic data are queried for each ZCTA through the US Census Bureau's 2010 Census Demographic Profile (to include the 2009–2013 American Community Survey). This data is segmented into variables of interest for each ZCTA to include: total population, total number of males, total number of females, occupied housing units, number of owner or renter occupied units, number of people living alone, number of males living alone, number of males over 65 living alone, number of females living alone, number of females over 65 living alone, median income, median age, percent single family detached (%SFD) homes, and educational attainment.

The information from the demographic profile is then paired with total energy consumption data (combined gas and electric) for each ZIP code in the San Antonio service area. The ZIP codes analyzed in this study are all located within Bexar County and are within a query range from 78201 to 78264. Of those 63 ZIP codes 54 are validated for analysis and the rest are removed. The 9 ZIP codes removed are either not numerically created by the US Postal Service; the area contained a military base, airport, golf course, and is non-residential; or, it yielded insufficient gas and electric consumption data. Specifically gas, since the local electric utility does not supply gas to the entire County limit. Monthly electricity and natural gas consumption information, aggregated at the ZIP code level, was provided by the local electric utility. Data was provided for a period of just over 48 months starting in December of 2009 and ending in January of 2014. This study utilizes consumption data from 2010 by Zip to pair with corresponding socioeconomic and demographic information from the last US Census.

Monthly electricity, in kilowatt-hour (kWh), and natural gas consumption, in one hundred cubic foot (CCF), are converted to British thermal units (Btu) as a common unit of measure. Annual electricity and natural gas consumption are estimated based on monthly consumption records as per Eqs. (1) and (2), below.

$$\begin{aligned} \text{Monthly Electricity (kBtu)} &= \text{Monthly Electricity (kWh)} \\ &\quad \times (3413 \text{ Btu/kWh}) \\ &\quad \times (1 \text{ kBtu}/1000 \text{ Btu}) \end{aligned}$$

$$\begin{aligned} \text{Monthly Gas (kBtu)} &= \text{Monthly Gas (CCF)} \\ &\quad \times (100,000 \text{ Btu/CCF}) \\ &\quad \times (1 \text{ kBtu}/1000 \text{ Btu}) \end{aligned}$$

$$\text{Total Electricity (kBtu)} = \Sigma(\text{Monthly Electricity})_{\text{Jan-Dec}} \quad (1)$$

$$\text{Total Gas (kBtu)} = \Sigma(\text{Monthly Natural Gas})_{\text{Jan-Dec}} \quad (2)$$

Total annual energy consumption is then calculated, at the Zip code level, as shown in Eq. (3).

$$\text{Total Energy (kBtu)} = \text{Total Electricity} + \text{Total Gas} \quad (3)$$

Socioeconomic and demographic variables explored in this study and the corresponding segmentation brackets developed to compare energy utilization patterns across categories are presented in Table 1.

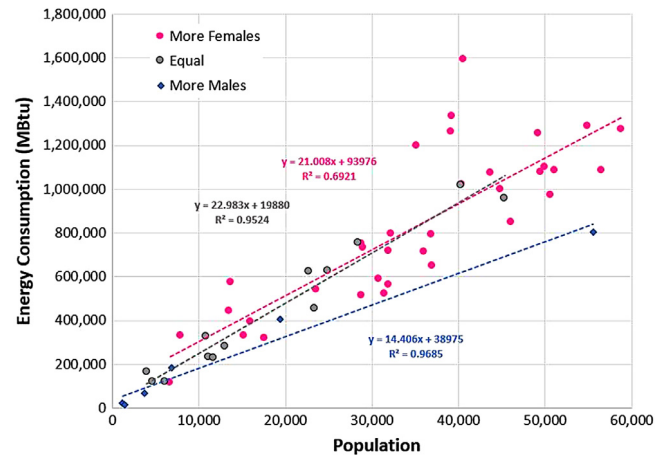


Fig. 1. Influence of population on total energy consumption.

4. Results and discussion

Total population and energy use are strongly related, $r(53) = 0.899$, $p < 0.001$. Linear regression analysis is used to investigate if population can predict total energy consumption (MBtu). A significant regression equation is found ($F(1, 52) = 219.26$, $p < 0.001$), with an R^2 of 0.808. The effect of population on resulting energy consumption remains strong even when segregating the Zip codes based on the male to female ratio, as seen in Fig. 1. Similar, significant regression equations are found for population in Zips with more males ($F(1, 4) = 122.93$, $p < 0.001$), with an R^2 of 0.968; population in Zips with “equal” number of males and females ($F(1, 11) = 220.30$, $p < 0.001$) with an R^2 of 0.952; and, population in Zips with more females ($F(1, 33) = 74.19$, $p < 0.001$), with an R^2 of 0.692.

There are a total of 795,490 female residents and 756,895 male residents in the 54 Zip codes validated for analysis within Bexar County with a mean of 14,731 females and 14,017 males per ZIP code. The majority of the 54 validated ZIP codes are female dominant (27) with only six male dominant ones, generally located in and around downtown.

4.1. Impact of male to female ratios

To further investigate the impact of gendered population on energy consumption, male to female ratios are plotted in Fig. 2. ZIP codes with more females (ratio < 0.95 , $M = 864,919$ MBtu, $SD = 384,457$) use significantly more total energy than Zip codes with more males (ratio > 1.05 , $M = 250,547$, $SD = 309,071$), $t(9) = 4.20$, $p = 0.002$. Zip codes with more females ($M = 25,252$ kBtu, $SD = 7245$), also use significantly more energy per capita than Zip codes with more males ($M = 18,520$ kBtu, $SD = 6113$), $t(8) = 2.35$, $p = 0.046$. Moreover, Zips with more females ($M = 67,353$ kBtu, $SD = 16,600$), use significantly more energy per home than Zip codes with more males ($M = 47,772$ kBtu, $SD = 18,403$), $t(7) = 2.40$, $p = 0.048$.

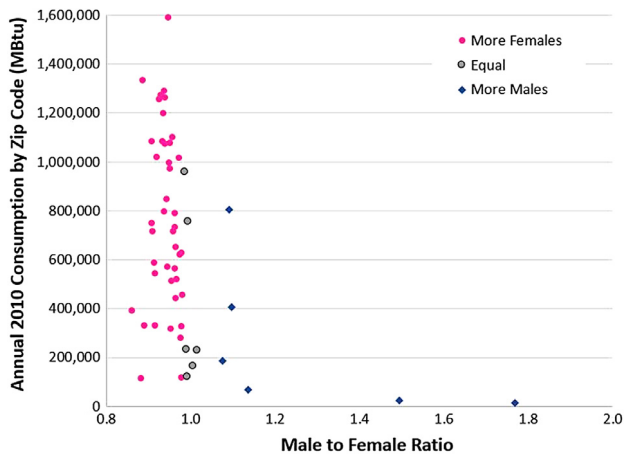


Fig. 2. Gender influence on total energy consumption.

As shown in Fig. 2, ZIP codes with more females dominate the +1,000,000 MBtu (MBtu—one million British thermal units) and higher total annual energy consumption brackets. On average, female predominant ZIP codes use about 865,000 MBtu while male predominant ZIP codes use about 251,000 MBtu. In comparison, ZIP codes with equal male to female ratios have a mean consumption of about 545,000 MBtu. Although gender is a central concept that receives much theoretical attention in the sciences, most of this inclusion is focused on statistical control (McCright, 2010). “Given gender’s consistent effects on several dimensions of environmental concern in past studies (e.g. Blocker and Eckberg, 1997; Davidson and Freudenburg, 1996; McStay and Dunlap, 1983; Mohai, 1992) and its enduring influence on climate change knowledge and concern documented in this study, future climate change public opinion research may benefit from richer theoretical tests of the effects of gender” (McCright, 2010). This focus is easily transcended to a gendered approach in managing energy at the individual household level (Elnakat and Gomez, 2015).

In addition to gender, demographic research links both urbanization and population aging to energy use patterns. An aging population may reduce long-term emissions by up to 20% in industrialized settings through a decrease in economic productivity and overall consumption since age structure also influences investment and Gross Domestic Product (Hunter and O’Neill, 2014; Liddle, 2000).

4.2. Impact of median age

Median age and both per capita energy use ($r(52) = 0.702, p < 0.001$) and energy use per home ($r(52) = 0.538, p < 0.001$) are strongly related. To further explore the relationship between per capita energy consumption and median age, a linear regression analysis is performed. A significant regression equation is found ($F(1, 51) = 49.68, p < 0.001$), with an R^2 of 0.493, as shown in Fig. 3.

Zips with median age less than 30 years old (9 Zip codes, $M = 19,801$ kBtu, $SD = 2949$) use significantly less energy per capita than Zips with median age above 40 years old (7 Zip codes, $M = 34,433$ kBtu, $SD = 7622$), $t(7) = -4.46, p = 0.003$. Similar significant difference in energy consumption per home is found for Zips with median age below 30 years old ($M = 58,347$ kBtu, $SD = 8013$) and Zips with median age above 40 years old ($M = 82,216$ kBtu, $SD = 20,437$), $t(7) = -2.71, p = 0.03$.

The observed increase in energy consumption in Zips with median age above 40 years old can be attributed to amount of hours spent in the home, life stage of residents (married versus single, school age children versus young or no children),

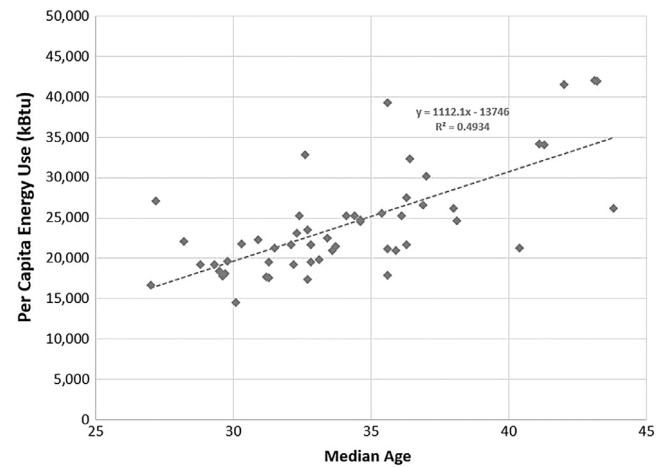


Fig. 3. Median age influence on per capita energy consumption.

acquisition power (median income_{MedAge>40} = \$71,134, median income_{MedAge<30} = \$47,549), composition of the building stock (owner to renter ratio = 2.4 versus 1.5), and educational attainment (45% Bachelor’s or higher versus 24%), respectively. There is only one Zip code with median age above 50 years old, 78 205, which was removed from this analysis because it is clearly an outlier. This Zip code has relatively few housing units, mostly males (two thirds of the population), mostly renters, with a median income of just \$13,705.

Older people (aged 65–79) according to Liddle and Lung (2010) will probably spend more time at home and therefore consume more residential energy. In addition, Sarrow and Crenshaw (2014) confirm “that adults (as the most economically active in any population) are more likely to increase energy demands quite independently of overall population size...” indicating that energy consumption will increase as society ages (Zagheni, 2011; and also see Menz and Kuhling, 2011).

4.3. Impact of educational attainment

Research shows that in China education is a strong predictor of environmental concern. The higher levels of education lead to more environmentally oriented behaviors across gender and especially with age (Xiao and Hong, 2010). However, with education comes higher income where building stock purchased by that income capital takes precedence to energy consumption influences. Previous research has shown that in San Antonio, Texas, larger newer homes tend to consume more energy even though they are more efficient in terms of energy consumption per square foot (Gomez et al., 2014; Elnakat et al., 2015). This is mainly a function of house size and the amount of energy used to condition the space and the probable more lenient behavior in conservation of the household. Usually, the higher the standards of living, the more resources are consumed per capita and the lower the carrying capacity will be (Giampietro et al., 1992).

Educational attainment and energy consumption are strongly related. Educational attainment, measured as the percentage of the population with a high school diploma or less, is strongly related to both per capita energy consumption ($r(53) = -0.747, p < 0.001$) and energy consumption per home ($r(53) = -0.577, p < 0.001$). Higher levels of education result in higher levels of consumption. Educational attainment measured as percentage of the population that have obtained at least a bachelor’s degree is strongly related to both per capita energy consumption ($r(53) = 0.777, p < 0.001$) and energy consumption per housing unit ($r(53) = 0.599, p < 0.001$). To further explore the relationship between the two variables, a linear regression analysis is performed. A significant

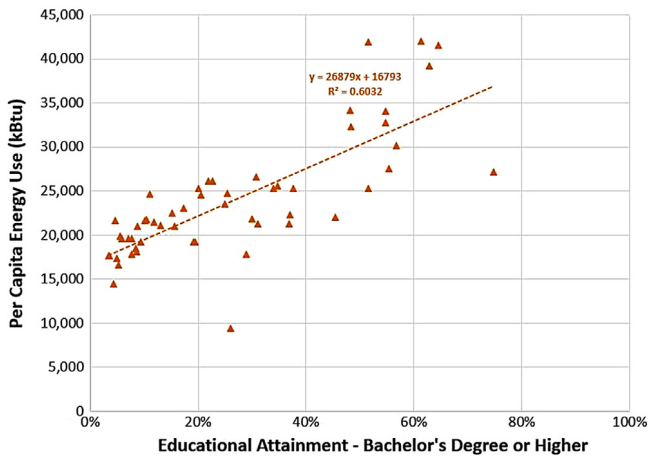


Fig. 4. Educational attainment influence on per capita energy consumption.

regression equation is found ($F(1, 52) = 79.04, p < 0.001$), with an R^2 of 0.603, as seen in Fig. 4.

Similar linear regression analysis is conducted to investigate the relationship between per capita energy consumption and lower levels of educational attainment (measured as %HS or less). A significant regression equation is found ($F(1, 52) = 65.66, p < 0.001$), with an R^2 of 0.558.

Zips with lowest levels of educational attainment (>63% HS or less, $M = 432,354$ MBtu, $SD = 282,083$) consume significantly less total energy than Zips with highest levels of education (<41% HS or less, $M = 728,112$ MBtu, $SD = 429,927$), $t(37) = -3.12, p = 0.003$. Furthermore, Zips with lowest levels of educational attainment ($M = 18,589$ kBtu, $SD = 1851$) consume significantly less energy per capita than Zips with highest levels of education ($M = 27,771$ kBtu, $SD = 7180$), $t(32) = -6.26, p < 0.001$. Zips with lowest levels of educational attainment ($M = 58,282$ kBtu, $SD = 5141$) also consume significantly less energy per home than Zips with highest levels of education ($M = 72,578$ kBtu, $SD = 18,466$), $t(33) = -3.75, p < 0.001$.

Zips with high levels of educational attainment (>37.5% bachelor's or higher, $M = 32,539$ kBtu, $SD = 6694$) use significantly more energy per capita than Zips with lower levels of education (<21.5% bachelor's or higher, $M = 20,152$ kBtu, $SD = 2570$), $t(15) = -6.67, p < 0.001$. Similarly, Zips with high levels of educational attainment ($M = 84,433$ kBtu, $SD = 15,401$) use significantly more energy per home than Zips with lower levels of education ($M = 60,067$ kBtu, $SD = 4801$), $t(14) = -5.78, p < 0.001$.

4.4. Impact of median income

In general, higher income results in higher energy consumption. Median income and both per capita energy consumption ($r(53) = 0.795, p < 0.001$) and per home energy consumption ($r(53) = 0.815, p < 0.001$) are strongly related. To further explore this concept, a linear regression analysis is conducted, as shown in Fig. 5. A significant regression equation is found ($F(1, 52) = 89.04, p < 0.001$), with an R^2 of 0.631, meaning that about 63% of the variability in per capita energy consumption can be explained by income levels. Similarly, energy consumption per home is related to median income. A significant regression equation is found ($F(1, 52) = 102.75, p < 0.001$), with an R^2 of 0.664.

Zips with the lowest median income (<\$30,000, $M = 17,393$, $SD = 3526$) consume significantly less energy per capita than Zips with the highest median income (>\$45,000, $M = 28,552$, $SD = 7161$), $t(28) = -5.95, p < 0.001$. Similarly, these same Zip codes ($M = 51,811$, $SD = 14,889$) also consume

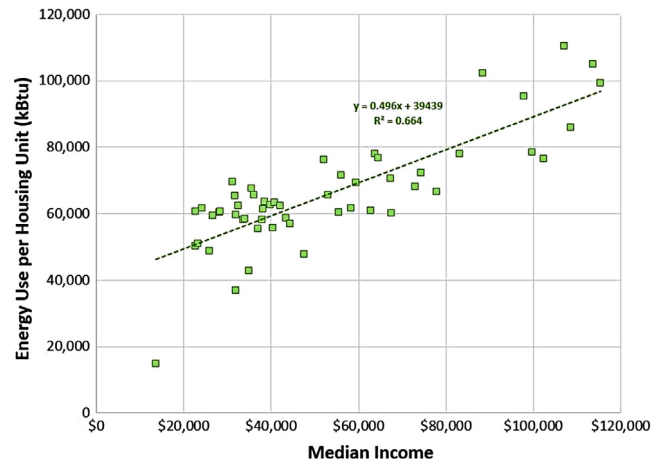


Fig. 5. Median income influence on energy consumption per housing unit.

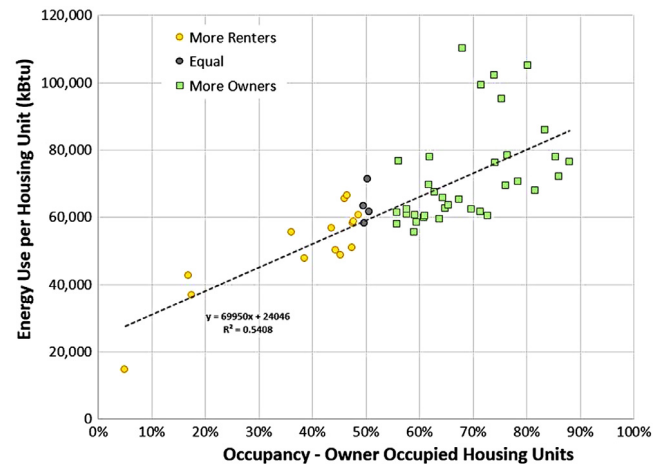


Fig. 6. Occupancy influence on energy consumption per housing unit.

significantly less energy per home than Zips with higher income ($M = 76,402$, $SD = 15,925$), $t(15) = -4.14, p < 0.001$.

The results of analyses performed confirm the strong relationship between income, educational attainment, householders' purchasing power, housing preferences and resulting energy consumption patterns. Upon further investigation, high energy consumption ZIP codes are also the most populated, contain higher median age populations, higher numbers of owner-occupied housing units, higher percentages of single-family detached homes, fewer individuals living alone, and have lower male to female ratios.

4.5. Impact of occupancy

Zip codes are divided into three groups based on the percentage of owner-occupied housing units. To investigate the relationship between energy consumption per home and percentage of housing units that are owner-occupied a linear regression analysis is conducted, as shown in Fig. 6. A significant regression equation is found ($F(1, 52) = 61.25, p < 0.001$), with an R^2 of 0.541. Zip codes with higher percentage of owner-occupied housing units (>55% and >1.25 Owner to Renter ratio) represent about 67% of the total number of housing units, 72% of the total energy consumed by all Zip codes, 72% of the population and approximately 76% of the total number of single-family detached housing units within the study area.

In this study, Zips with higher percentages of owner occupied housing units ($M = 25,130$, $SD = 7262$) consume significantly

more energy per capita than Zips with higher percentage of renter occupied housing units ($M = 20,603$, $SD = 4940$), $t(35)$, $p = 0.016$. Similarly, these same Zip codes ($M = 71,476$ kBtu, $SD = 14,595$) consume significantly more energy per home than Zips with fewer owner-occupied housing units ($M = 50,900$ kBtu, $SD = 13,343$), $t(26)$, $p < 0.001$. Residential energy consumption will increase with urbanization as more people are connected to the grid. “On the other hand, if increases in urbanization mean more people living in multiple family and especially high-rise buildings, then less energy should be consumed on a household basis compared to people living in single family, detached housing” (Liddle and Lung, 2010).

4.6. Impact from other variables

The study also investigates a potential relationship between housing type, population density and energy utilization. As expected, since the ZIP codes validated for this study are mainly residential areas, the %SFD home distributions among the validated ZIP codes range from 60% of the total number of housing units to over 90%. This is an indication of San Antonio's building stock. The majority of the households in San Antonio live in single-family detached homes. Renters mainly occupy apartment dwellings, and in some instances rent single-family detached homes, single-family attached homes or multifamily units. There are minimal high-rise buildings in San Antonio, Texas; however, this trend will start emerging with more core urban dwellers as the population increases and cities continue efforts to revitalize and redevelop downtown areas.

Zip codes with high numbers of single-family detached units (>60% SFD, $M = 69,937$, $SD = 14,656$) consume significantly more energy per home than Zips with the lowest number of SFD units (<40% SFD, $M = 39,398$, $SD = 15,483$), $t(5)$, $p = 0.009$.

A similar pattern is observed with regards to population density across the study area. Population densities in a typical San Antonio household in this study range between 1.75 to 3.65 people per housing unit. According to the 2010 US Census, average household size in Bexar County is 2.75 while average family size is 3.33. Zip codes with low population densities (<2.5, $M = 28,536$, $SD = 9697$) consume significantly more energy per capita than Zip codes with high population densities (>3.0, $M = 19,775$, $SD = 2810$), $t(15)$, $p = 0.005$.

5. Conclusion

A multidisciplinary approach that combines the social sciences, engineering, and other technical fields will help develop needed strategies for mitigating the impacts of rapid population growth and increased demands for energy, water, transportation, buildings, food and health services. A total of 54 residential ZIP codes represent the service area of this study within the City of San Antonio, Texas. The resulting analyses of this study provide evidence of the co-dynamic influence of socioeconomic and demographic variables on energy utilization, aggregated at the Zip code level, by revealing:

(a) ZIP codes with more female residents than male residents statistically and significantly use more energy annually. Female dominated ZIP codes consume a mean total energy of 769,848 MBtu annually while ZIP codes with more males use 250,547 MBtu and ZIP codes with a 1:1 male to female ratio use 410,268 MBtu. When normalizing these aggregated values per capita and per household, the conclusions remain the same, where female dominant households consume more energy (Figs. 1 and 2).

- (b) The ZIP codes with a majority female population dominate the +1,000,000 MBtu and higher annual energy consumption brackets (Fig. 2).
- (c) Energy consumption increases significantly around the median age of 40–55 at the ZIP code level, which is the highest median age bracket within the study.
- (d) Higher levels of educational attainment and income result in significantly higher levels of energy consumption per capita and per home.
- (e) Zip codes with higher percentage of owner-occupied housing units (>55%) use significantly more energy per capita and per home than Zip codes with lower percentages of owner-occupied homes (<49%).
- (f) The majority of San Antonio residents included in this study live in single-family detached homes. Zip codes with higher population density (>3.0) consume significantly less energy per capita than Zip codes with lower population densities (<2.5).

The practical applications of the marriage of socioeconomic and demographic data with housing characteristics and energy consumption can be used as a set of predictive analytics tools to better provide a targeted approach to effective demand side management of residential energy and aid public policy efforts in support of energy efficiency and conservation.

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References

- Abrahamse, W., Steg, L., 2009. How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? *J. Econ. Psychol.* 30, 711–720.
- Arora, S., Cason, T., 1999. Do community characteristics influence environmental outcomes? Evidence from the toxics release inventory. *South. Econ. J.* 65 (4), 691–716.
- Bingham, R., Zhang, Z., 2001. *The Economies of Central-City Neighborhoods*. Westview Press, Boulder, CO.
- Blake, B., Bentov, L., 2001. Geographical mapping of unmarried teen births and selected socio-demographic variables. *Public Health Nurs.* 18 (1), 33–39.
- Blocker, T., Eckberg, D., 1997. Gender and environmentalism. *Soc. Sci. Quart.* 78, 841–858.
- Brounen, D., Kok, N., Quigley, J., 2012. Residential energy use and conservation: Economics and demographics. *Eur. Econ. Rev.* 56, 931–945.
- Davidson, D.J., Freudenburg, W.R., 1996. Gender and environmental risk concerns. *Environ. Behav.* 28, 302–339.
- Domene, E., Sauri, D., 2006. Urbanisation and water consumption: influencing factors in the metropolitan region of Barcelona. *Urban Stud.* 34 (9), 1605–1623.
- Elnakat, A., Gomez, J.D., 2015. Energy engenderment: An industrialized perspective assessing the importance of engaging women in residential energy consumption management. *Energy Policy* 82, 166–177. <http://dx.doi.org/10.1016/j.enpol.2015.03.014>.
- Elnakat, A., Gomez, J.D., Roberts, J., Wright, M., 2015. Big data analysis of swimming pools' impact on household electric intensity in San Antonio, Texas. *Int. J. Big Data Intell.* 2 (4), 250–261.
- Fourtney, J., Rost, K., Warren, J., 2000. Comparing alternative methods of measuring geographic access to health services. *Health Serv. Outcomes Res. Methodol.* 1 (2), 173–184.
- Giampietro, M., Bukkens, S., Pimentel, D., 1992. Limits to population size: Three scenarios of energy interaction between human society and ecosystem. *Popul. Environ.* 14 (2), 109–131.
- Gomez, J.D., Elnakat, A., Wright, M., Keener, J., 2014. Analysis of the energy index as a benchmarking indicator of potential energy savings in the San Antonio, Texas single family residential sector. *Energ. Effic.* <http://dx.doi.org/10.1007/s12053-014-9310-6>. 10/29/2014.
- Gram-Hanssen, K., Kofod, C., Petersen, K., 2004. Different everyday lives: Different patterns of electricity use. In: American Council for an Energy Efficient Economy. (1–13).
- Grubestic, T., 2008. Zip codes and spatial analysis: Problems and prospects. *Soc.-Econ. Plann. Sci.* 42, 129–149.

- Hunter, L., O'Neill, B., 2014. Enhancing engagement between the population, environment, and climate research communities: the shared socio-economic pathway process. *Popul. Environ.* 35 (3), 231–242.
- Johnson, G., 2004. Small area mapping of prostate cancer incidence in New York State (USA) using fully Bayesian hierarchical modelling. *Int. J. Health Geograph.* 3, 29.
- Levinson, A., Niemann, S., 2004. Energy use by apartment tenants when landlords pay for utilities. *Resour. Energy Econ.* 26, 51–75.
- Liddle, B., 2000. Population growth, age structure, and environmental impact. *Popul. Environ.* 21 (4), 385–411.
- Liddle, B., Lung, S., 2010. Age-structure, urbanization, and climate change in developed countries: revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. *Popul. Environ.* 31 (5), 317–343.
- Lutzenhiser, L., 1993. Social and behavioral aspects of energy use. *Annu. Rev. Energy Environ.* 18, 247–289.
- McCright, A., 2010. The effects of gender on climate change knowledge and concern in the American public. *Popul. Environ.* 32 (1), 66–87.
- McStay, J.R., Dunlap, R.E., 1983. Male–female differences in concern for the environmental quality. *Int. J. Women's Stud.* 6 (4), 291–301.
- Menz, T., Kuhling, J., 2011. Population ageing and environmental quality in OECD countries: evidence from sulfur dioxide emissions data. *Popul. Environ.* 33 (1), 55–79.
- Misra, K., Goggins, K., Matte, A., Lewis, A., 2014. Understanding teen mothers: A zip code analysis. *Amer. Econom.* 59 (1), 52–69.
- Mohai, P., 1992. Men, women, and the environment. *Soc. Nat. Resour.* 5, 1–19.
- Scarrow, R., Crenshaw, E., 2014. The ecology of energy use: using the POET model to analyze consumption and intensity across nations 1970–2000. *Popul. Environ.* (September).
- Skobba, K., Bruin, M., Yust, B., 2013. Beyond renting and owning: The housing accommodations of low-income families. *J. Poverty* 17 (2), 234–252.
- Steck, D., Baynes, S., Noack, A., 1996. Regional and local variation of indoor radon and radon source potentials. *Environ. Int.* 22 (1), 729–737.
- Steg, L., 2008. Promoting household energy conservation. *Energy Policy* 36, 4449–4453.
- Sutherland, R., 1991. Market barriers to energy-efficiency investments. *Energy J.* 12 (3), 15–34.
- The News, 2012. Energy use increasing with home sizes. *Air Cond. Heat. Refrig. News* 46 (3), 4.
- US Census Bureau, 2010. ZIP Code Tabulation Areas (ZCTAs). *Geography*, Cited 29 November 2014. Available via <https://www.census.gov/geo/reference/zctas.html>.
- US Census Bureau, 2015. QuickFacts: San Antonio city, Texas, Cited 15 December 2015. Available via <http://www.census.gov/quickfacts/table/PST045214/4865000.00>.
- Wiggins, M., McKenney, K., Brodrick, J., 2009. Residential energy monitoring. *ASHRAE J.* 51 (6), 88–89.
- Xiao, C., Hong, D., 2010. Gender differences in environmental behaviors in China. *Popul. Environ.* 32 (1), 88–104.
- Zagheni, E., 2011. The leverage of demographic dynamics on carbon dioxide emissions: Does age structure matter? *Demography* 48 (1), 371–399.