THE DETERMINANTS AND TRENDS IN THE HOUSEHOLD ENERGY CONSUMPTION FOR DIFFERENT END USES IN THE UNITED STATES DURING 2001-2009

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DEDICATION

This dissertation is dedicated to my dear dad, Karuppusamy Kumarasamy. Thank you for providing me with everlasting inspiration to succeed in life.

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by

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The focus of this study is a broad examination of the residential energy consumption for the use of appliances, space heating, space cooling, and water heating in the United States over the period 2001-2009. For the purpose, the Residential Energy Consumption Survey (RECS) data sets from the years 2001 and 2009 were used. This analysis of the household energy consumption for each of the end uses has been carried out in two stages: the first was to identify the determinants of energy consumption and the second was to use these determinants to examine trends in the residential energy consumption. Specifically, linear regression models were used to identify the determinants and these were subsequently used in a regression based decomposition analysis to analyze trends in the household energy consumption for each end use during 2001-2009.

The study shows that the overall variation in household energy consumption in the United States is determined by the census divisions, race/ethnic categories, housing types, fuel types, freezer, dryer, dishwasher, computer, number of color televisions, type of heating equipment, type of air conditioning equipment, size of water tank, and building vintage categories. The number of rooms in the household, household size, household income, urban/rural categories and age of the householder also emerged as major factors in determining the variation in the household energy consumption. Though there is an overall increase in the household energy consumption for appliance use and space cooling over the period 2001-2009, energy efficient appliances played a crucial role in decreasing the household energy consumption for these end uses over the above period. In the case of space heating and water heating, there is a considerable decrease in the overall household energy consumption, suggesting that the energy efficiency of buildings and of heating equipment played an important role in the overall decrease in the household energy consumption.

Based on the analysis and the outcome, the study finds the need for policy intervention both at local level and federal level for energy conservation in household energy consumption. The suggested policy is to provide information to households at the local level in order to make the right purchase decisions on energy efficient appliance and equipment. The study further suggests the need for federal policies for improved minimum performance standards for appliances, stricter building codes for energy efficient homes, and for educating consumers in energy saving behaviors to reduce residential energy consumption. In addition, federal policies for energy conservation targeting minority groups like Black, Hispanics, elderly people and children to reduce the total household energy consumption are also recommended.

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CHAPTER ONE: INTRODUCTION

The study of household energy consumption in the United States (U.S.) assumes its importance in the light of the fact that the residential section represents approximately 22% of the total U.S. energy consumption and 21% of total carbon emissions (EIA, 2009a and EIA, 2009b). Since the early 1970s, total residential sector energy use has declined to about 15% while at the same time overall consumption grew to 22% due to increase in population. As compared to the year 1978, in 2005 the total energy use in U.S homes occupied as primary residences decreased slightly from 10.58 quads to 10.55 quads (RECS, 2005). This marginal reduction in the use of residential energy was attained despite a 45% increase in number of homes, 38% increase in central air conditioning, 8% increase in cloth washing machines, and 24% increase in dishwashers. These are contradicting findings and are difficult to reconcile with the observed trends in the household energy consumption in the U.S.

Patterns household energy consumption are determined by various other factors as illustrated by the following historical perspective. Since 1970s, the residential total per capita energy use leveled off due to a decrease in the use of gas and an increase in use of electricity for space heating (Battles, 1995). The increase in electricity consumption can be attributed to several factors. The foremost reason is due to the increase in air conditioning use, both in volume of space conditioned as well as hours of usage. Other factors such as switching from gas pumps to electric pumps and from gas water heaters to electric water heaters, and migration to the South (Schipper, 1989) contributed to the increase in electricity usage. The shift from gas to electricity was also aided by governmental policies for rural electrification (e.g., Tennessee Valley Authority), which subsidized electricity in Southeast, Northwest and elsewhere (Cooper, 1998).

These shifts in energy product substitutes, in demography and the governmental policies can potentially explain part of the observed trends in the household energy consumption.

A major factor in the household energy consumption is the increase in the surface area of houses and a decrease in the size of a household in the U.S. Concretely, in the period from 1970 to 2005, the United States saw an increase in the volume and surface area of houses along with an increase in the number of household appliances and their usage. During this period the house floor area increased from 1500 square feet in 1970 to 2266 square feet in 2000. In the case of household appliances, electronic items and their usage such as televisions, DVD players, and computers showed a remarkable increase (NAHB, U.S. census 2000). During the same period, the household size decreased from 3.14 to 2.63 (ACS 2009). In addition, the U.S. population growth is another important determinant of household energy consumption. Over the above period, the population grew at the rate of 22% resulting in more household energy consumption per capita.

The preceding discussion shows that the household energy consumption is not dictated one or few simple factors, and results in the complexity seen in estimating the patterns and trends in the residential energy consumption. The scenario also demands a close look and complete investigation in to other related factors such as aging, changes in life style, changes in household composition, income, climatic conditions, building characteristics, equipment efficiency, and the type of energy used for different end uses. Such a unified analysis is required to track and understand the patterns and trends in the residential energy consumption. Thus, this dissertation research is guided by the core question, namely how the changes in demographic, building structure and behavioral characteristics of the household causes or influences the shifts and changes in the household energy consumption in the United States?

Research Problem

Most of the current research in U.S household energy consumption focuses on a specific aspects, such as space heating, space cooling, water heating and use of appliances at a given point of time using a specific dataset that pertains to a particular year. Most of these studies also utilize data that corresponds to a smaller area such as metropolitan city or a state but not using data that is representative of the entire nation. Furthermore, in these studies, the interests are either the estimation of household energy demand or the household energy consumption with respect to one or at the most, a few of the following factors: household characteristics, house structure characteristics, behavioral patterns, cultural patterns, and climatic conditions. More importantly, most of these studies do not include the changes in household energy consumption patterns over time. Therefore, these studies do not provide any insights in to the *variation over time* in household energy consumption due to the changes in the aforementioned factors.

To fill in these gaps in the household energy consumption research, this study attempts to model the patterns and trends in the household energy consumption for each end use over the last decade using various empirical methods. For this purpose, the household energy consumption is examined during the time period from 2001 leading up to 2009 and accounts for a broad range of factors. These factors may finally explain the variation in the household energy consumption due to various end uses such as space heating, space cooling, water heating and the use of appliances coupled with various demographic factors, building structure, and behavioral characteristics of the householders. To this end this study uses nationally representative data sets for 2001 and

2009 that incorporate a large number of relevant explanatory variables to determine the extent to which the factors related to demographic, building structure and behavioral characteristics of the householders influence the variation in energy consumption in U.S. households.

Research goals

The main questions examined in this study are as follows.

1) What are the current demographical, building structural, and behavioral factors associated with the different end uses of the household energy consumption in U.S?

2) Are there significant differences in the household energy consumption for different end uses in different geographic areas such as Census Bureau designated divisions?

3) Are there significant changes in race/ethnic in the household energy consumption in different end uses over time since 2001?

4) Is there a shift in household energy consumption from other sources of energy consumption in the households (such as natural gas, liquefied petroleum gas etc) to electrical energy in different end uses over time since 2001?

5) To what extent are the changes in the factors associated with the household energy consumption influence the changes in the household energy consumption for different end uses over time since 2001?

Research motivation

Many past studies have sought answers for above questions. The links between demographic, building structure, and behavioral factors associated with the different end uses of the household energy consumption in the United States have been widely explored. Household consumption of energy for space heating and cooling, appliances and other energy services are directly or indirectly influenced by a number of demographic factors such as household size, age structure and levels of urbanization (O'Neill et al., 2001; Schipper, 1996; Poulsen and Forrest 1988; Schipper et al., 1989).

A study on energy consumption and appliance ownership found that domestic appliance ownership is linked to the level of income and education held by the householder. The study indicated a clear connection between the socio-economic status of the householder and the household energy consumption and concluded that those with higher education and income are more likely to own freezers, washing machines, microwaves, tumble dryers and dish washers (Leah et al., 2009).

It is widely agreed today that occupant energy behavior has a major influence over the household energy consumption. A system approach model found that occupant behaviors are highly pattered and has an impact on household energy consumption in the context of family schedules and comfort preferences (Weihl and Gladhart, 1990). It has been also found that the role of occupant behavior such as thermostat setting, frequency of air conditioning use, and number of cooled rooms act as significant drivers of change in household energy consumption. These behavioral patterns appeared to become more significant in times of stable energy prices than during the times when the energy prices were rising rapidly (Kempton and Schipper, 1994).

The household energy consumption is closely related to structure and type of the building. There are numerous studies that have made use of the relationship between the building characteristics (age of the building, total area, constructed area, type of materials used for walls and roofs, number of doors and windows, number of bedrooms, type of insulation) and the residential energy consumption for space heating and space cooling (Steemers et al., 2009; Hausfather et al., 2009, Chong, 2010). Some of these variables, such as total area, constructed area, and number of bedrooms tends to change depending on the type of housing units. The three basic categories of housing type are single-family units (both as detached and attached units), multifamily (both low-rise and high-rise apartments) and mobile homes and average number of rooms differ for each type of family unit (Diamond, 2001).

However, it is clear that most of these studies have not assessed the changes in energy consumption over time due to changes in the aforesaid factors and to a larger extent they are the studies applicable only to a certain epoch, and are therefore inadequate to understand the energy consumption patterns over an extended period. For example, in the last two decades the widespread use of electronic items in the U.S. has increased the consumption of electrical energy. Furthermore, electricity is used as the prime energy source for air-conditioning and there is an increase in the number of households with central air-conditioning in the two decades preceding 2001 (EIA, 2005). These changes in the household energy consumption have not received adequate attention from researchers.

Yust et al., 2002 and Dziobinski, 1999 are examples of a few studies in the past, which include analysis of the U.S residential energy consumption. However these studies do not feature the recent trends in the residential energy consumption, while other studies focus on trends in residential energy consumption in the developing countries. Further these studies do not focus on residential energy consumption for different end uses. Similarly, some studies explain the variation in the household energy consumption based on family life cycle, race/ethnic groups and cultural practices (Lutzenizer et al., 1992 and Hacket et al., 1991). These studies too, mainly focus on the general variation in residential energy consumption due to combinations of environment, building and social characteristics but not with specific reference to different end uses.

One other inadequacy in previous works is that the analysis of energy consumption focused on a specific aspect. These may be typical geographical areas such as city or state or a typical end use or on demand forecasting of energy consumption. Analysis of the relationship between energy consumption, climate and housing characteristics is another example (Kaza, 2010; Lam et al., 2009 and McNeil, 2009). It is therefore clear that the changes in household energy consumption in totality over time, and in relation to all these factors or the variation in residential energy consumption among various geographical areas in the U.S have not been addressed.

In summary, this research will address these shortcomings in the existing body of research work on residential energy consumption, focusing on variations, trends and changes in the household energy consumption, with particular reference to space heating, space cooling, water heating and use of appliances. To this end, this study makes use of the variables related to demographic, socio-economic, behavioral and housing characteristics, for different census designated areas in the U.S using Residential Energy Consumption Survey starting from 2001 to 2009.

CHAPTER TWO: BACKGROUND AND LITERATURE

Eco System theory on residential energy consumption

Theories detailing the potential correlates of residential energy consumption are concentrated largely in technology, economics, and psychology and sociology literatures. The technological perspective of residential energy consumption focuses on characteristics of buildings and appliances to determine the energy consumption. The economic perspective views the occupants of the household as an entity to study and understand the household energy consumption. The psychological perspective of residential energy consumption tries to understand the influence of individual perceptions about actions related to energy use, energy services, and environment. The social perspective of residential energy consumption employs social origins to understand the variability and patterns of household energy consumption (Mithra Moezzi et al., 2010). However, none of these individual approaches suffice to understand the variability, patterns and trends in the household energy consumption. For this purpose, it is necessary to have a theory that encompasses the concepts of various disciplines just outlined. This can be accomplished by choosing ecosystem theory, which is an offspring of systems theory, as the guiding outline for this study.

A system is an ensemble of interacting parts where change is seen as a transformation of the system in time, which conserves its identity with growth, steady state, and decay as its major types of changes. In a system, goal oriented behavior characterizes the changes observed in the state of the system (Chen et al., 1993). Hence the major proposition of the human ecosystem theory is that goal oriented interactions occur among the parts of human ecosystem that include the human organism and its three environments - the natural environment, the social environment, and the designed environment. This framework makes it possible to study several interactions or effects simultaneously, justifying the implicit assumption that the humans are not completely isolated but interdependent with other parts of the system – i.e the environments. This study uses this ecosystem approach to model the household energy consumption by examining the various factors of the household system and their relationship to energy consumption (Yust et al., 2002).

The ecosystem model was owes its origins to Guerin (1992) and it was adapted from the findings of Bubolz, Eicher, and Sontag (1979) and Morrison (1974). In the study of residential energy consumption using ecosystem model the components as follows:

The Natural Environment (NE) comprises both the physical and biological components. Attributes of this kind and those that pertain to our energy consumption study include climate, which can be measured by the number of days requiring heating or cooling.

The Human Organism (HO) can be an individual (occupant), family, or household. Attributes of this relevant to our study are the size of the household, age of the occupants, and gender.

The Social Environment (SE) includes the psychological and social behavior of the occupants. Attributes of this type that are closely related to our study are sense of comfort, cultural norms and race/ethnicity.

The Designed Environment (DE) includes anything constructed or built or designed by humans. Age of the house, size of the house, and the number of appliances (Guerin, 2000) are attributes of this kind that are relevant to this study.

The basic thrust of the framework mentioned above is that the various environmental factors interact with human factors, which in turn result in the variation seen in the household energy consumption. As an illustration, consider the number of children, adults and seniors (HO) living in a home designed for their convenience (DE). Their day-to-day indoor activities (SE) such as cooking, watching TV, using computer and listening music consume energy. The variation or the change in the amount of energy consumption in a household depends on the climatic condition, hot or cold (NE), and the household activities (SE) of the occupants (HO) and any change in one environment can affect the manner in which the household consumes energy. Thus, increase in the number of occupants or purchase of a new electrical appliance or change in the climatic condition or increased activities that use energy in the household will bring in the variation or change in household energy consumption (Yust, 2002 and Guerin, 2000).

Thus the use of human ecosystem theory in the study of household energy consumption provides a suitable platform to identify how various components of aforesaid environments interact with each other affecting the household energy consumption decisions that cause changes and variation in the household energy consumption over time.

Residential energy consumption – Literature review

Human Organism variables

Age

Age is closely related to household energy consumption as illustrated in the following. An analysis of the thermostat settings found that day time thermostat settings were significantly higher for households with elders and young children (Peters, 1990). Another study on occupant behavior found that households with infants and elderly residents reportedly maintaining higher room temperatures during the winter (Weihl et al., 1990). However, there are several contradictory findings. For example, a study on energy conservation reported that age is not a significant factor in energy conservation in the households (Eichner and Morris, 1984). Similarly, a policy implication study on household energy consumption and electricity prices found that younger households tend to reduce the consumption of electricity when there is an increase in the price of electricity. Yet another study on housing needs and age found that occupant age was correlated to the mean monthly electric usage and that older occupants used less electricity. Further, a study on energy consumption by the elderly found that those aged 65 years and older used about one third less electricity on the average than the people whose age was less than 65 years.

Gender

There has not been much research in to energy consumption differences and gender in the developed countries (Clancy et al., 2003). Demographic trends suggest that more women than men live in poverty, as single parent or alone as elderly, suggesting that energy consumption is restricted to their household budget (Clancy et al., 2003). Further, single male and single female households also demonstrate a divergence in types of appliances owned. For instance, women tend to have more appliances related to household such as washing machines while men tend to have more electronics items such as computers and cell phones (Clancy et al., 2003). Another study found that behavioral changes aimed at reducing household energy consumption disproportionately affect women, especially those with younger children and also have to work outside of home. The main effect was the stress due to the increased workload (Carlsson et al., 2007).

Race/ethnicity

Race/ethnicity is an important variable in the study of patterns and trends of household energy consumption in the United States. Quantitative studies of ethnic energy use patterns, as well as in-depth ethnographic studies of household energy consumption within different cultures, show energy consumption differentials can also follow from cultural practice (Lutzenhiser et al., 1992, Kohno et al 1984). Differential price and policy impacts on low-income minority households also have been identified, particularly among African Americans (Brown, 1977; Brazzel et al., 1979 and Lutzenhiser, 1992). A recent study found that African-Americans consistently consumed substantially more natural gas in their households than White Americans (Auda et al., 2011). Yet another study reported significant variations in the consumption patterns of electricity, natural gas, fuel oil, and LPG by Latino and non-Latino households in the United States.

Household income

Influence of income on energy consumption is well recognized in the literature on the subject. Household income assumes importance in predicting patterns and trends on household energy consumption since the household income is affected by the up and down turns in national economy. However, there are opposing conclusions drawn by the researchers on this issue in various studies. On the one hand it has been suggested that higher the household income lower the energy consumption in the households. For instance, a study in Australia (Lenzen et al., 2006) found that households with higher income tend to purchase services and equipments which are less energy intensive resulting in a lower consumption. On the other hand, another study found that households with lower income live in aged houses with little insulation and use lower energy efficient appliances resulting in higher household energy consumption (Clancy et al., 2003). Similarly, it has been suggested that households with higher incomes tend to possess more number of household appliances and electronic items resulting in higher household energy consumption (O'Neil et al., 2002 and Abrahamse et al., 2009). In any case, it can be inferred that the income's influence on the household energy consumption is significant hence cannot be ignored.

Education

In some earlier work, it was found that higher education is positively associated with energy conservation consciousness thus resulting in lower household energy consumption (Black et al., 1985 and Hogan, 1976). However, recent studies indicate an inconclusive relationship between education and household energy consumption. A study of household energy saving measures found a positive relationship between education and household energy consumption (Poortinga et al., 2004). Another study of consumer behavior found that education is not significantly related to household energy consumption (Gatersleban et al., 2002). Yet another study concluded that appliance ownership is related to householder's education resulting in higher household energy consumption. This trend has been attributed to the positive correlation between education and income (Leahy et al., 2009).

Household size

Earlier researches identified that the number of people in the household is a determinant of the pattern and the amount household energy consumption, with an increase in the number accounting for greater energy consumption (Steemers, 2009 and Johnson et al., 1987). A study on demographic determinants of household energy use found that two person households use about 17% less energy per person than do a single person households, and three person households use more than a third less energy per person than do people living alone (O'Neil et al., 2002). Similar findings were also reported in other studies on energy consumption and economies of scale and on direct and indirect energy requirements in the households (Vringer et al., 1995 and Ironmonger et al., 1995). This pattern in household energy consumption might be due to economies of scale or might be a combination of other household characteristics such as income and age. Hence understanding the relationship between household energy consumption and household size is crucial in the analysis of patterns and trends in the household energy consumption.

Home Ownership

The ownership of a home is a strong predictor of trends and changes in the household energy consumption. Many earlier studies found that the consumers who owned the house engaging in various energy conservation practices (Archer et al., 1986; Gmelch et al., 1988 and Stern et al., 1985). It was also found that consumers who own their homes are more likely to have many energy conservation features in their homes because of the personal benefits from the investment. They were also more responsive to more energy conserving long-term capital investments (Black et al., 1985 and Johnson et al., 1987). A study that compared the energy consumption in owned and rented dwelling found that electricity consumption in owned dwellings is similar to that of rented dwellings. In the case of other types of energy, the consumption in owned dwellings was consistently lower than the consumption in the rental counterparts (Lucie Maruejols et al., 2010). Home ownership coupled with the inhabitant's income and education exhibit a complex relationship in the household energy consumption. A study on reduction in energy consumption behavior found that homeowners who had only primary education were more likely to undertake only non-investment measures than investment measures compared to those who had higher education and higher income. Homeowners with secondary education were more likely to adopt other high investment energy efficiency measures compared to those with university education (Nair et al., 2010).

Natural Environment variables

Rural and urban differences in energy consumption

Energy consumption patterns and trends over time are also influenced by the differences in rural and urban differences in energy consumption. These differences arise due to the effect of heat island, which is created when concrete and asphalt replace soil and plants on a large scale — this can therefore make cities more expensive in summer and cheaper in winter. Since it takes more energy to heat most homes than to cool them, this tends to benefit chilly Northern cities more than balmy Southern ones. It has been estimated that cities have the lowest annual energy use per household (85.3 million BTUs) and household member (33.7 million BTUs) of all four categories. Rural areas consume about 95 million BTUs per household each year, followed by towns (102 million) and suburbs (109 million). Similarly, urban families as a whole spend at least $30 billion more for energy each year than their country counterparts, but each individual urban family actually spends about $200-$400 less. That suggests that urban homes are more numerous but also more efficient (DOE, 2009). Such differences in household energy consumption indicate urban and rural divide is an important factor in the study of patterns and trends in the household energy consumption.

Energy price

Studies on energy consumption acknowledge that energy consumption is influenced by price and the patterns and trends over time changes with the change in price. A study that analyzed aggregate of electricity consumption in San Diego and Los Angeles during 2000 reported much smaller energy consumption changes in response to an increase in price (Bushnell and Mansur, 2005). One experimental study in Los Angeles found that an increase in price by 150% for 100 households resulting in an average decline of 6.2% electricity consumption (Acton and Mitchell, 1980). A similar study in San Diego found an average decline of 13% in the household energy consumption in response to a price increase by 130% (Reis et al 2008). Another study on energy consumption with respect to household income and price for the period 1997-2007 in the United States, found that initial response to an increase in energy price brought an immediate decline in energy consumption and later declining monotonically (Alberini et al., 2010), indicating the influence of price on household energy consumption.

Heating Degree Days (HDD) and Cooling Degree Days (CDD)

Climatic condition is important factor in the analysis of patterns and trends in the household energy consumption over time. It derives its importance in accounting for the household energy consumption for space conditioning and, to some extent, water heating. Cooling degree days (CDD) and heating degree days (HDD) are climate variables that indicate for the number of days the average temperature is above or below a certain threshold (65 Degree Fahrenheit) and the actual deviation. In the US, HDDs are larger than CDDs, and heating is the largest consumption category, followed by water heating in residences. However, for locations such as Texas and Florida, both of which have more than 2000 CDDs and less than 4000 HDDs, the proportion of energy used in air conditioning use is higher than the rest of the country. This study tries to analyze the effects of these variables on changing patterns and trends in the household energy consumption.

Social Environment and energy consumption

Occupant behavior is an essential component in the study of trends in the household energy consumption. In models of residential energy use, the effects of occupant behavior are often approximated using an assumption about the average or typical behavior. However, in practice there is a wide variation in household energy consumption that can be attributed to the occupant's behavior. A study on occupant behavior found that household energy consumption is related to many different aspects of family life and thermostat setting and water use patterns are intimately tied to patterns of household occupancy, family waking and sleeping schedules, and mealtimes (Weihl et al 1990). Yet another study found that the human behavioral factors of time, physical effort and attention, general convenience and thermal comfort, varied with strategy of household energy use, with no one strategy being both the convenient to use or producing a most thermally acceptable environment (Turner et al., 1993).

Designed Environment variables

Total constructed area

The total constructed area of the house is an important factor in predicting the trends and changes in the household energy consumption over time. For example, the physical size of the single family homes have increased from 1,645 square feet in 1970 to 2,400 square feet or more in 1996, and over the same period the number of houses built with 1,200 square feet or less decreased (NAHB, 1997). The increase in physical size of the house was accompanied by more energy consuming household appliances and resulted in higher household energy consumption. This connection has been supported by many earlier studies that predicted higher household energy consumption with increase in the physical size of the dwelling (Hewett et al., 1988; Johnson et al., 1987 and Ritche et al., 1981).

Age of the building structure

Age of the building structure is an important factor in the analysis of energy consumption trends in the United States. In the United States the homes built between 2000 and 2005 used 14% less energy per square foot than homes built in the 1980s and 40% less energy per square foot than homes built before 1950. However, larger home sizes have offset these efficiency improvements. Again, a third of all homes built before 1950 are located in the Northeast; since then, majority (51%) of new homes was constructed in the South (DOE, 2009). Obviously, trends in the U.S. residential building sector are expected to be reflected in the household energy consumption.

Insulation of building envelopes

Building structure plays an important role in energy consumption and improvements in building materials, home designs, and insulation materials are some contributing factors. Insulation of building envelopes, both opaque and transparent, is the most important strategy for building energy conservation. Insulation of walls, roof, attic, basement walls and even foundations is one of the most essential features of energy-efficient homes. One such excellent insulation material is glass. Glass is used as transparent insulating envelopes in windows and skylights and significantly reduces heat loss and gain during the winter and summer. Thus, type of walls, roofing materials, and number of windows all contribute to household energy consumption (Kim et al., 2009).

House type

Housing type is another key variable in tracking the patterns and trends in the household energy consumption. According to the 2005 Residential Energy Consumption Survey (RECS), approximately 80 percent of residential energy consumption is by single-family homes while 15 percent is by multifamily dwellings and the remainder by mobile homes. The data show that an average multifamily unit uses half the energy of an average single family detached home. Most residential energy use goes to space heating, thus smaller units in multifamily buildings that share walls and require less heating and cooling and thereby consume less energy than single-family detached homes. Most of the earlier studies have included housing types in the household energy consumption studies (Steemers et al., 2009; Maruejols et al., 2010 and Ritche et al., 1981 and Hausfather et al., 2009).

Household appliances and energy consumption

The ensemble of electrical appliances in the household is another factor and demands a close scrutiny in the analysis of household energy consumption. Refrigerators (99.9%), cooking appliances (99.9) and color television (98.9) are very common irrespective of the household income. Even in the lowest income bracket, i.e. households having less than $15,000, more than half the households have cable or satellite television, a stereo system, or a VCR and the households with large screen televisions in lowest income bracket has increased from 25% to 43%. The percent of households that have a clothes washer and cloth dryer increased from 45%

for the lowest income level (income less than $15000) to 92% for the highest income level (income $75000 or more). The households with dishwashers increased from 18% for lowest income to 83% for homes with highest income level and the housing units with more than one refrigerator increased from 6% to 31%. Besides, there is a considerable increase in the number of freezers, computers, and electric coffee makers in the U.S. households (RECS 2001). Such an enormous change in scenario results in a greater variability in the household energy consumption, especially the energy consumption in the form of electricity.

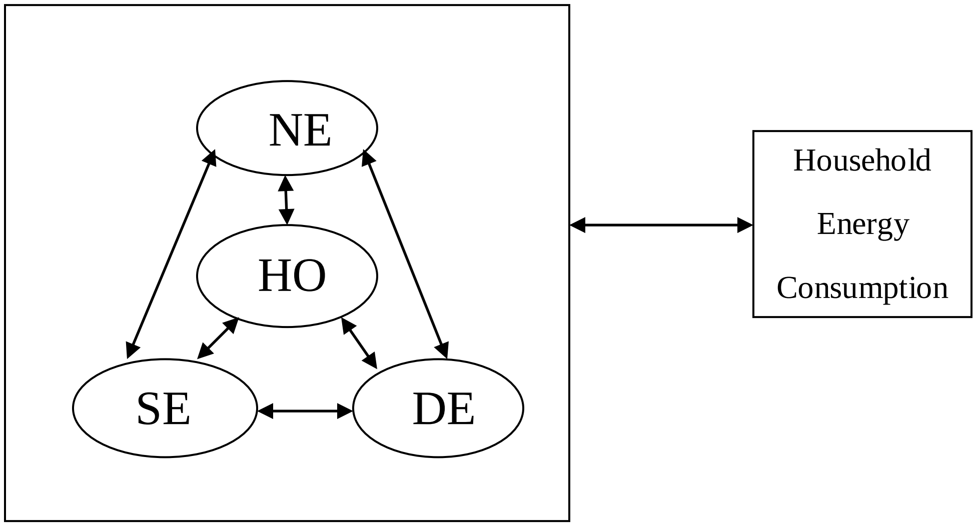

Figure 1 Eco-system model for household energy consumption

Examples for eco-system constituents:

NE: Natural Environment – Geographical location, energy price, urbanity, heating degree days and cooling degree days.

SE: Social Environment – Thermostat setting preferences, washing preferences, and dishwasher usage patterns.

DE: Designed Environment – Number of rooms in the household, type of insulation, stock of household appliances, and number of light bulbs in the household.

HO: Human Organism – Race/ethnicity, age and gender of the householder, household income, and household size.

Energy consumption: Energy consumption for appliance use, space heating, space cooling and water heating individually.

Factors influencing different end-uses

Space heating

In the literature on energy consumption, several alternative approaches are used to model the residential energy consumption for different end use. In addition, different predictor variables are used depending on the nature of study and availability of variables. A study on production and consumption of residential space heat using econometric modeling have employed family size, constructed area, heating degree days, household income and price of the fuel as predictor variables and this study found that all these predictor variables are statistically significant in the model (Klein, 1988). Another study on energy consumption for space heating using discrete-continuous approach made use of income, heating degree days, age of the dwelling, age of the householder, dwelling size, and average energy price and these variables were found statistically significant in the model (Nesbakken, 2001). In another study on determinants of household's space heating using discrete choice analysis included number of children at home, householders' education, rural, and household size in addition to variables mentioned earlier. It was found that the household size, number of children at home and householder's education were statistically significant (Braun, 2010). Yet another study on determinants of space heating expenditures found that the variables quantifying owned and rented homes were statistically significant but the variables pertaining to baths and windows were not statistically significant in the model (Rehdanz, 2007). The study on residential energy end use characteristics using log-linear model included the behavioral variables on thermostat setting, heating equipment age, wall types, race/ethnicity, and floor type and it found all these variables were statistically significant in the model (Hausfather et al., 2010).

Space cooling

In models used in household energy consumption for cooling usually make use of all those variables used in the study of space heating. The only difference in this case is that the variable pertaining to heating degree days replaced by a variable that reflects the cooling degree days. A study on household energy consumption using generalized linear model for cooling, found that the age of the house and the number of windows were not statistically significant in the model. The study also found that type of cooling, cooling degree days, household size, age of the householder, income, type of house, floor area and number of rooms cooled were statistically significant in the model (Steemers et al., 2009). Another study on residential energy end use characteristics found that all these variables including variables number of children in home, and urban were also significant in the model (Hausfather et al., 2010).

Water heating

In the energy consumption models for water heating, those variables that correspond to space heating are used. However, in studies that aim to predict energy consumption for this end use do not find that these variables are significant in the model. A study on end use characteristics using log-linear model found that energy consumption used for water heating in the households were statistically related variables to of householder's age, total number of rooms, electricity price, race/ethnicity, heating degree days, householder's income, household size, dishwasher and washing temperature (Hausfather et al., 2010).

Use of appliances

In the modeling of energy consumption of appliances, one usually includes refrigerators, washing machines, televisions, and air conditioners. These appliances cover most of the end uses that low and middle income households can afford (McNeil et al., 2010). A study using multiple regression analysis made use of a variety of household appliances such as number of refrigerators, freezers, microwave ovens, gas grill, dish washer, clothes washer, dryer, toaster, number of color televisions, exhaust fan, ceiling fan, computer, fax printer, copier, cordless telephone, and answering machine (Yust et al., 2002). A different study on the dynamic energy consumption indicators for domestic appliances found that lighting, refrigerator and dishwasher were the appliances that consumed most energy in the households (Wood et al., 2002).

Fuels used for different end uses at homes in the United States

Energy required for households in the United States are drawn from various sources such as electricity, natural gas, liquefied petroleum gas, coal, and wood etc. depending upon the sources available at the geographical location. Other factors that influence the nature of energy source are the type of the appliances used, type of equipment to heat/cool, and the technology used for various household devices. Of these, electricity and natural gas remain as main fuel source in the residential energy consumption (RECS, 2009).

In the U.S. out of a total of 113.6 million homes 69.4 million homes use natural gas, 48.9 million use propane/LPG, 13.1 million use wood, 7.6 million use fuel oil, 1.7 million use kerosene, and 1.2 million use solar energy and all homes use electricity for any end use (RECS, 2009). Of those homes that use electricity for space heating, 38.2 million use electricity as their main source where as 26.8 million homes use electricity as their secondary source. Electricity is also used for air conditioning in 94.0 million homes, for water heating in 47.1 million homes, and for cooking in 71.2 million homes (RECS, 2009). Of those homes that use natural gas for any end use, 55.6 million homes use natural gas as their main source and 7.2 million homes use natural gas as their secondary source for space heating. In the case of natural gas usage, 58.5 million homes use gas for water heating and 39.2 million homes use it for cooking (RECS, 2009). Of those homes that use propane/LPG for any end use, 5.6 million homes use propane/LPG as their main source and 2.8 million homes use propane/LPG as their secondary source for space heating. Further, 4.2 million homes use propane/LPG for water heating and 5.6 million homes use propane/LPG for cooking (RECS, 2009). Of those homes that use wood for any end use, 2.8 million homes use natural gas as their main source and 8.8 million homes use wood as their secondary source for space heating (RECS, 2009). Of those homes that use fuel oil for any end use, 6.9 million homes use it as their main source and 0.4 million homes use it as their secondary source for space heating (RECS, 2009). Of those homes that use kerosene for any end use, 0.5 million homes use it as their main source and 0.9 million homes use it as their secondary source of energy for space heating (RECS, 2009).

Household energy consumption for each end use is specified in British Thermal Units (BTUs) in the categories of electricity, and natural gas. The sources such as liquefied petroleum gas, coal, wood are used as the dependent variable in this study in order to maintain uniformity in the analysis. The kilowatt-hour (KWH) is a standard unit of electricity production and consumption and as such it does not provide a common ground for comparison of different forms of energy consumption in the households.

Modeling techniques in residential energy consumption – Overview

The various modeling techniques employed in household energy consumption can be put in two categories grouped as top-down and bottom-up. The terminology corresponds to hierarchical position of data inputs as compared to residential sector. The top-down models employ an estimate of the total residential sector energy consumption and other variables to describe the energy consumption based on the characteristics of the entire housing sector. In contrast bottom up models estimate the energy consumption of individual or groups of houses and then extent these results to represent a larger geographical area (Swan et al., 2009).

Top-down approach

This approach considers the residential sector as a sink and does not distinguish energy consumption due to individual end uses. This type of modeling is used to study the effect on energy consumption due to ongoing changes or transitions within the residential sector, usually to determine the energy supply requirements. Top down models utilizes macro-economic variables such as gross domestic product (GDP), employment rates, price indices, variables corresponding to climatic conditions, housing construction and demolition rates, estimates of appliance ownership, and the number of units in the residential sector. The strengths of top down modeling are the need for aggregate level data, which is readily available from various sources, and historic residential sector energy values. The drawbacks of this model are the lack of detail regarding the energy consumption of individual end uses, which eliminates the advantage of key areas of energy consumption for policy issues (Swan et al., 2009).

Bottom-up approach

In this type of modeling, the input data is more granular than the housing sector as a whole. These models account for the energy consumption of individual end uses, individual houses, or groups of houses and are then extended to represent geographical area of interest. The nature of data inputs depends on the type of bottom-up model chosen (Swan et al., 2009).

In practice there are two types of bottom-up models in the household energy consumption studies, the first employs statistical methods while the other employs engineering methods. Statistical methods rely on historical information and the type of regression analysis that is used to attribute household energy consumption to particular end uses. Once the relationship between end uses and energy consumption are identified, the model can be used to estimate the household energy consumption. In contrast engineering methods explicitly account for the energy consumption of end uses based on power ratings and use of equipment and systems and/or heat transfer and thermodynamic relationship (Swan et al., 2009).

Some of the other variables commonly used in the bottom-up models are the those that are related to the dwelling properties such as building structure, building envelop characteristics, demographic information of the household, equipment and appliances, climatic conditions, and occupant behavior. This high level of detail is the strength of bottom-up modeling and gives it the ability to model and determine energy consumption for each end use to identify the areas of improvement (Swan et al., 2009).

Research Hypotheses

Now based on our discussion of eco-system theory related to household energy consumption the research questions in Chapter-1 can be rephrased as research hypotheses. The research hypotheses are as follows:

Hypothesis-1:

H1 (Research Hypothesis): The current demographic factors, building structure factors, and behavioral factors are associated with the different end uses of the household energy consumption in the United States.

Hypothesis-2:

H1 (Research Hypothesis): There are significant differences in the household energy consumption for different end uses in different geographic areas such as Census Bureau designated divisions in the United States.

Hypothesis-3:

H1 (Research Hypothesis): There are significant changes in race/ethnic and socioeconomic differences in the household energy consumption in different end uses over time since 2001.

Hypothesis-4:

H1 (Research Hypothesis): There is a shift in household energy consumption from other sources of energy consumption in the households (such as natural gas, liquefied petroleum gas etc.) to electrical energy in different end uses over time since 2001.

Hypothesis-5:

H1 (Research Hypothesis): The changes in the factors associated with the household energy consumption influence the changes in the household energy consumption for different end uses over time since 2001.

CHAPTER THREE: DATA DESCRIPTION AND METHODOLOGY

Introduction

Data for this study are from the information compiled by the Energy Information Administration (EIA) of the Department of Energy from the 2001 and 2009 Residential Energy Consumption Surveys (RECS) (EIA, 2005a). The data were collected from a representative national sample of all housing units, including single-family homes, apartments, and mobile homes, occupied as the primary residence in the 50 states and the District of Columbia. The surveys were designed to provide information concerning energy consumption within the residential sector. The information regarding energy-conserving techniques and household data were collected through personal interviews with the heads of the households. Data concerning actual energy consumption were obtained from records of the energy suppliers. The survey design, sampling procedure, and data collection for these surveys have remained fairly constant across the RECS surveys and are available from the EIA (RECS, 2001 and RECS, 2009).

Survey sample design

In the multistage area probability design, the universe of the sample is divided into successively smaller, statistically selected areas. The process begins with the selection of primary sampling units (PSUs) and ends with the selection of individual households. PSUs are either metropolitan areas containing a central city of 50,000 or larger population, or they are counties or groups of counties containing small cities and rural areas. In the sample design the total land area of the 50 States and the District of Columbia was divided into a number of PSUs. The primary stratification of PSUs resulted in nine census divisions. Each strata were separately defined within Census divisions for the four most populous states (California, Florida, New York, and

Texas) and for two states with unique weather conditions (Alaska and Hawaii). Stratification was also based on MSA (Metropolitan Statistical Area) or non-MSA status of PSUs and, to the extent feasible, on dominant residential space-heating fuel and weather conditions. PSUs were grouped into a number of strata's with one PSU selected from each stratum. From these PSUs the secondary sampling units (SSUs) were selected.

The SSUs, usually eight or more were selected from each PSU in such a manner that each SSU consisted of one or more of census blocks, selected directly from the census statistics. Further, blocks were combined, as necessary, to create SSUs that contained at least 50 housing units. SSUs that contained very large numbers of housing units were divided in to smaller listing segments and one listing segment was selected for detailed address listing. The addresses of these housing units were placed in a database for actual sample selection. Finally, the ultimate clusters were formed by choosing specific addresses from each of the field listings and a cluster of housing units, selected at random by the computer from the penultimate cluster that were assigned to the interviewers (RECS, 2001 and RECS, 2009).

Data organization in RECS

The RECS provides detailed information on the energy utilization in residential buildings in the United States. The information obtained through household survey includes physical characteristics of the housing units, the appliances, the demographic characteristics of the household, environmental characteristics of the geographical location of the housing unit, types of the fuels used, behavioral patterns in energy use and other relevant detailed information that related to the energy use in the U.S. households. The information obtained through energy suppliers survey (energy suppliers identified through household survey) includes the types of fuels supplied and billing records on actual energy consumption of households. This information is then grouped in to various categories such as housing unit characteristics, kitchen appliances, home appliance and electronics, space heating, water heating, air conditioning, miscellaneous uses such as lighting, windows, and efficiency related improvements, fuels used, housing unit measurements, fuel bills, and household characteristics in a manner to provide in-depth information on residential energy consumption (RECS, 2001 and RECS, 2009).

Estimation of energy consumption in RECS for each end use

Besides this information, RECS also uses a statistical process that uses the billing data of the household to estimate the housing unit's energy consumption and energy expenditure for the year in which the survey is conducted. This estimated energy consumption is employed with an end use model to break down the total annualized consumption and expenditures for each sampled case into portions used for space heating, air-conditioning, water heating, refrigerators, appliances, and other uses. RECS employ separate models in 2001 and 2009 for electricity, natural gas, fuel oil, LPG/propane, and kerosene. These estimates are used in this study as the outcome variable to model different end uses. Subsequently these models were used to analyze the patterns and trends in the household energy consumption over time (RECS, 2001 and RECS, 2009).

Decomposition Method

Introduction

This study uses regression based Binder-Oaxaca decomposition analysis to predict the determinants and trends in the household energy consumption at two different points in time, for years 2001 and 2009. In the original application, economists used the regression based composition methods to assess the differences in wages between whites and blacks and the relevant attributes were found to be educational attainment and work experience. The analysis was further used to assess the racial differences in these attributes, and how these affected the wages. Of late, the regression method has found applications in other fields as well, like sociology and health sciences (Sunil et al., 2013 and Dubowitz et al., 2011). In the current study, we analyze differences in household energy consumption for different end uses based on regression based decomposition analysis.

A very important step in the analysis of trends in household energy consumption is to look for differences in household energy consumption at different points over time. If there were differences in consumption then the next step would be the measure them using an appropriate method. Furthermore, the method proposed should not only allow us to measure such differences in consumption but also provide an option to explain the difference in terms of the contributing factors. This requirement in the analysis of trends in the household energy consumption demands the decomposition method, which identifies the differences in household energy consumption at different points over time and also explains it in terms of the contributing factors. The basic idea of using this method is to explain the difference in outcome variable in question by a set of factors that vary systematically over time. For, example the differences in household energy consumption may be explained by variations in household size, number of rooms, household appliances, energy efficiency in appliances due to improvements in technology, household income, and the use of electronics. The decomposition method can reveal the extent of differences in household energy consumption at different points over time that can be explained by the difference in, say income rather than the difference in household size. The decomposition method used in the analysis of household energy consumption is based on regression analysis of the relationship between the energy consumption variable of interest and its correlating factors. The decomposition method when used with regression analysis not only reveals the association of household energy consumption with various factors but also provides a statistical explanation for causal effects of the relevant factors with household energy consumption.

Decomposition method - An overview

Consider two linear regression models with an outcome variable Y and having the same set of predictors. In our discussion we may consider this as the household energy consumption for the end use of space heating in the years 2001 and 2009. In this case, the outcome variable will be the logarithm of energy consumption and the predictors would be variables corresponding to the building structure, environment, and demographics. Here, the interested is finding out the difference in mean outcome of household energy consumption for the end use space heating. The difference in mean outcome D, will be

$$D=E\ (Y_{2009}) - E\ (Y_{2001}) \qquad (1)$$

where E (Y) denotes the expected value of the outcome variable.

Based on linear regression model we have,

$$Y_{2001}=X_{2001}'\beta_{2001} + \varepsilon_{2001},\ E\ (\varepsilon_{2001}) = 0 \qquad (2)$$

$$Y_{2009}=X_{2009}'\beta_{2009} + \varepsilon_{2009},\ E\ (\varepsilon_{2009}) = 0 \qquad (3)$$

where X is a vector containing the predictors and the constant β contains the slope parameters and the intercept, and ε is the error. Now, the mean outcome difference can be expressed as the difference in the linear prediction at the year-specific mean of the predictors. That is,

$$D = E(Y_{2009}) - E(Y_{2001}) = D = E(X_{2009}'\beta_{2009} + \varepsilon_{2009}) - E(X_{2001}'\beta_{2001} + \varepsilon_{2001})$$

$$D = E(Y_{2009}) - E(Y_{2001}) = E(X_{2009})'\beta_{2009} - E(X_{2001})'\beta_{2001} \quad (4)$$

Since by assumption,

$$E(\beta_{2001}) = \beta_{2001}, \quad E(\beta_{2009}) = \beta_{2009}, \quad E(\varepsilon_{2001}) = 0, \text{ and } E(\varepsilon_{2009}) = 0$$

Now the contribution of differences in predictors to the overall outcome difference, that is the difference in household energy consumption for the end use space heating in the equation (4) can be rearranged as,

$$\mathbf{D = [E(X_{2009}) - E(X_{2001})]'\beta_{2001} + E(X_{2001})'(\beta_{2009} - \beta_{2001}) + [E(X_{2009}) - E(X_{2001})]'(\beta_{2009} - \beta_{2001})} \quad \mathbf{(5)}$$

As seen in the equation (5) the outcome difference is divided in to three components

$$D = E + C + I \quad (6)$$

Where, the first component

$$E = [E(X_{2009}) - E(X_{2001})]'\beta_{2001} \quad (7)$$

is the part that corresponds to difference in the expected outcome due to the differences in the predictors.

The second component,

$$C = E(X_{2001})'(\beta_{2009} - \beta_{2001}) \quad (8)$$

is the part that corresponds to the difference in the expected outcome due to the differences in the coefficients including the differences in the intercept.

The third component,

$$I = [E(X_{2009}) - E(X_{2001})]' (\beta_{2009} - \beta_{2001}) \qquad (9)$$

is the part that accounts for differences in the expected outcome due to the differences in predictors and coefficients that exist simultaneously (Blinder, 1973).

Statistical Method

This study uses bottom-up statistical approach with log-linear models to study influence of each predictor variable on the dependent variable. This approach is ideally suited to identify closely associated factors with each end use of household energy consumption and to recover the finer details related to the end use of household energy consumption (Swan et al 2009). Specifically, log-linear models based on ordinary least square (OLS) method will be used with predictor variables such as energy price, household characteristics, housing unit characteristics, geographical characteristics, appliance ownership and use pattern, and heating/cooling degree-days. Earlier work on energy consumption statistical modeling found that log-linear models provide higher adjusted R-squared values and smaller confidence intervals for a selected range of predictor variables. Besides, it was also found that in energy consumption modeling the normal probability plot of residuals is well behaved for log-linear models as compared to the normal probability plot of residuals for linear models (Jihoon Min et al., 2010). Dependent variables in each of the four regressions are natural log values of household energy use for space heating, water heating, use of appliances, and space cooling. Residential Energy Consumption Survey provides the estimated energy consumption for each end use and for each surveyed household for years 2001 and 2009.

The statistical procedure begins with using log-linear models for each of end uses such as space heating, space cooling, water heating, and use of appliances to identify the current factors that determine the household energy consumption for the year 2009. These energy consumption models for the specific end use will also provide the extent to which the predictors influence the household energy consumption for that end use. Then using the same predictors with log-linear models, energy consumption for every end use will be modeled for the year 2001. Then the regression models for the years 2001 and 2009 will be compared using Binder-Oaxaca decomposition method to estimate the variation in consumption for the year 2009 as compared to the consumption for the year 2001 and the contribution of changes in the predictors toward the changes in consumption for each end use.

Categorizing Census divisions, race/ethnicity and fuel types

One of the main objectives of this study is to find out whether there are significant differences in the household energy consumption for different end uses in different geographic areas such as Census Bureau designated divisions in the United States. This objective necessitates the inclusion of variables that correspond to the census bureau designated divisions in the United States in the regression model. Thus the variables that correspond to this objective are the divisions mentioned in the following list:

New England (comprising the states Connecticut, Maine, Massachusetts, New Hampshire, Vermont, and Rhode Island), Middle Atlantic (comprising the states New Jersey, New York, and Pennsylvania), East North Central, (comprising the states Illinois, Indiana, Michigan, Ohio, and Wisconsin), West North Central (comprising the states Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota), South Atlantic (comprising the states

Delaware, the District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia), East South Central (comprising the states Alabama, Kentucky, Mississippi, and Tennessee), West South Central (comprising the states Arkansas, Louisiana, Oklahoma, and Texas), Mountain (comprising Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming) and Pacific (comprising states Alaska, California, Hawaii, Oregon, and Washington) of which the division Middle Atlantic is chosen as the reference division.

Another objective of this study is to find if any race/ethnic differences exist in the household energy consumption for different end uses. For this objective the variables that correspond to race/ethnicity are also included in the model. Race/ethnicity is made in to four categories namely, White, Black, Hispanic and other. The race/ethnic category White include all non-Hispanic whites, the category Black include all non-Hispanic blacks, the category Hispanics include those having their origin as Latin America, and all others remaining included in to the Other category of which the category White is chosen as the reference category. Similarly to compare the different kinds of fuels used in households for different end uses, the household fuels are made in to four major categories namely electricity, natural gas, liquefied petroleum gas, and the rest all are included in the category, “other fuels” of which the fuel electricity is chosen as the reference category. Further, the actual consumption of the fuels in the households is measured in British Thermal Units to maintain the uniformity in measurements among different types of fuels.

Variables selection

In linear regression models multicollinearity occurs when several of the predictor variables under consideration are highly correlated with other predictors. In such cases adding or removing a predictor changes estimated regression coefficients substantially, and hence changes the conclusions based on the model as well. To avoid multicollinearity in the household energy consumption modeling using log-linear models, the variables are selected from a range of variables, from those variables available in RECS, in such a manner that the correlation between any two variables is well below the value 0.5. Pearson correlation coefficient was obtained for each pair of predictor variables and those variables having correlation coefficient less than 0.5 were included in the model. When correlation coefficient is less than 0.5 the variance inflation factor of the variables are well under control resulting in a robust model (Jihoon Min et al., 2010).

The Regression Model

The Log-linear model employed in the study of determinants and trends in the residential energy consumption for each end use is as follows:

$$Y_{2001}=X_{2001}'\beta_{2001} + \varepsilon_{2001},\ E\left(\varepsilon_{2001}\right) = 0 \qquad (10)$$

$$Y_{2009}=X_{2009}'\beta_{2009} + \varepsilon_{2009},\ E\left(\varepsilon_{2009}\right) = 0 \qquad (11)$$

Where, Y_{2001} and Y_{2009} are the dependent variables in the models, which are the natural logarithms of energy consumption for the use of household appliances in units of thousand BTUs for the year 2001 and 2009 respectively. On the right hand side X's correspond to the predictors and β's correspond to the coefficients in the regression model.

CHAPTER FOUR: RESIDENTIAL ENERGY CONSUMPTION FOR APPLIANCE USE

Introduction

The past two decades in the United States have seen significant efforts to improve the energy efficiency of home appliances. This is supported by the drop in energy consumption in the past two decades, e.g. in the year 1993 showed a sharp decrease for all appliances, in 2001 for refrigerators and in 2003 for dishwashers (Bansal et al, 2011). Furthermore, the new and improved efficiency standards agreed by home appliance manufacturers in the United States will continue to reduce the energy consumption by household appliances. Particularly refrigerators, freezers, clothes washers, clothes dryers and dishwashers will be more efficient (DOE, Energy Conservation program, 2010). While such improvements in reducing the household energy consumption for appliances continue, the shift in appliance ownership from labor saving devices to entertainment and the increased use of consumer electronics in the households has partly offset gains made by efficiency of major appliances (RECS, 2009). In this context the current study of the household energy consumption for the use appliances assumes its importance.

This chapter is organized to arrive at results and conclusions logically consistent manner. We start with a description of dependent variable in the models for the years 2001 and 2009 followed by measurements of independent variables for these years. Following this, descriptive statistics and comparison of the independent variables in the models are presented to illustrate changes in these variables in year 2009 with respect to year 2001. The results of regression analysis for years 2001 and 2009 are presented in the following section and these results are discussed individually for years 2001 and 2009 with reference to earlier work. In the next section the results from regression based decomposition analysis are incorporated and detailed discussion is presented on the trends in the household energy consumption for appliance with special reference to the research hypotheses outlined in Chapter 1.

The following chapters on household energy consumption for space heating, space cooling and water heating are also organized in a similar fashion, as the procedure essentially remains the same as that presented in this chapter. In addition these procedures use the same variables that correspond to socio-demographic factors, environmental factors, and geographical divisions.

Dependent variable in the model

In the log-linear modeling of household appliance energy consumption, the outcome variable is the total amount of (estimated) energy used for the household appliances for years 2001 and 2009 in thousand BTUs. For the year 2001, the RECS provides the estimated appliance energy consumption for electricity, fuel oil, LP gas, kerosene and natural gas. Besides, RECS also provides the estimated electricity use for refrigerators and freezers for that year. Thus the total energy consumption for the appliance use for each household for the year 2001 in thousand BTUs will be as follows:

Energy consumption for appliance use for the year 2001

= *Use of electricity for appliances* + *Use of natural gas for appliances*

+ *Use of fuel oil for appliances* + *Use of LPG for appliances*

+ *Use of kerosene for appliances* + *Use of electricity for refrigerators*

+ *Use of electricity for freezers*

Unlike year 2001, in 2009 the RECS does not directly provide the energy consumed by appliances. Instead his has been included in the category of household energy consumption for other end uses. For electricity, it is the energy consumption for all other end uses excluding space heating, space cooling, water heating, and refrigeration. Similarly for natural gas, fuel oil, LP gas and kerosene, it is the energy consumption for all other end uses other than space heating and water heating. Along with these the amount of electricity used for refrigeration in thousand BTUs is included to obtain actual household energy consumption for the appliance use in each household (RECS 2009).

Energy consumption for appliance use for the year 2009

= Use of electricity for other end uses + use of natural gas for other end uses

+ Use of fuel oil for other end uses + Use of LPG for other end uses

+ Use of kerosene for other end uses + Use of electricity for other end uses

In the log-linear modeling of household energy consumed by appliances, the dependent variable is used as non-zero continuous variable in which energy consumption is measured in thousand BTUs.

Independent variables and their measurements

In the regression models, the first set of variables are those that correspond to census divisions, race/ethnicity, urbanity, fuels used for the main stove, use of light bulbs and housing types. The second set includes variables such as total number of rooms, number of household members, presence of separate freezer, dishwasher, dryer, aquarium, computer, fax, and number of color TVs. Since, the energy consumption for appliances in the household has no linear relationship with household members, a variable that correspond to square of household members is included in the model. Finally, the model also includes the average price of electricity paid by the household for the use of appliance during the surveyed year. This is useful because, households consume more electricity as compared to other fuels for the use of appliances and the relationship between energy consumption and price has been well documented (Acton and Mitchell, 1980 and Reis et al., 2008).

Both sets of variables mentioned above are measured as categorical variables. A third set of variables that represent the number of household members, number of lights turned on less than 4 hours per day, number of lights turned on more than 12 hours per day, number of lights on between 4 hours and 12 hours per day, total number of rooms and number of color televisions in the household are measured as the cardinal variables in the model and the age of the refrigerator is measured as the ordinal variable.

Descriptive statistics

Table-1 shows the distribution of survey samples across all variables used in this analysis. It can be seen from the table that the sample size for year 2009 survey is considerably larger, more than double the size of the sample for year 2001. The table indicates that there are no significant differences in the number of households interviewed among the census divisions except for South Atlantic Census division and Pacific Census Division. South Atlantic division includes 1.57% of more number of households during the year 2009 than the number of households for the year 2001 while Pacific division includes 0.59% more when compared year 2001 as compared to the year 2009. In both the samples a higher proportion of households are from South Atlantic Census division. Among the different housing types both samples include higher proportion of single-family detached homes. The sample for year 2009 includes 15.27% more of single-family detached homes as compared to the number of detached homes for the year 2001. Next to single-family detached households, both the samples have more number of households from apartments with 5 or more units in the surveys. The year 2009 has 0.93% more of such households as compared to the number of such households for the year 2001.

The proportion of race/ethnic differences in both the surveys is fairly equal except for the race/ethnic category pertaining to Hispanics. The sample for the year 2009 includes 6.84% more Hispanics households in the survey as compared to the year 2001. The urban/rural ratio is larger the sample for the year 2009 and it includes 5.77% more rural households as compared to the year 2001.

In the category of fuels used for the main cooking stove, the sample for the year 2009 shows a change in the energy sources from the sample for the year 2001. In the year 2009, it is clear that there is an increase in the use of electricity, natural gas and liquefied petroleum gas and a decrease in other types of fuels for cooking stove when compared the year 2001. The increase in the number of households in the 2009 survey that used electricity, natural gas and LPG gas as their stove fuel are 3.4%, 1.03% and 0.7% respectively.

In the case of other household appliances and electronics, the 2009 sample shows an increase in the use of dish washers, dryers and computers and decrease in the use of separate freezers, aquariums, and fax machines with reference to 2001 sample. The increase in the use of dish washers, dryers and computers for the 2009 sample are 7.4%, 5.8% and 19.8% respectively while decrease in the use of separate freezers, aquariums, and fax machines are 1.5%, 0.4% and 1.3% with reference to 2001 sample.

Table 2 provides the mean value for variables total number of rooms in the building, number of household members, number of color televisions, and age of the main refrigerators for the years 2001 and 2009. Besides, the table also shows lighting characteristics in the households for both the 2001 and 2009 samples. The mean values are fairly similar across both the samples. However, the mean number of rooms in the household shows huge decrease of 20.86% (1.56 rooms) in the sample for the year 2009 as compared to the mean number of rooms in the sample for the year 2001.

Table 1 Characteristics of categorical variables in the models for appliance use for years 2001 and 2009.

Variables	Year 2001 N=4813		Year 2009 N=12064	
	Number	Percentage	Number	Percentage
Census Divisions				
New England Division	244	5.05	586	4.85
Middle Atlantic Division	669	13.43	1623	13.43
East North Central Division	770	15.97	1899	15.71
West North Central Division	334	6.92	858	7.1
South Atlantic Division	916	18.99	2364	19.56
East South Central Division	307	6.37	753	6.24
West South Central Division	532	11.03	1358	11.24
Mountain Division	303	6.29	841	6.96
Pacific Division	747	15.5	1802	14.91
Housing Type				
Mobile Home	307	6.36	738	6.11
Single-Family detached	2844	58.96	7640	63.23
Single-Family attached	477	9.9	714	5.91
Apartments with 2-4 units	428	8.87	959	7.93
Apartments with 5 or more units	766	15.89	2032	16.82
Race/ethnicity				
White	3734	77.45	8337	69.11
Black	586	12.15	1550	12.83
Hispanics	259	5.37	1475	12.21
Others	242	5.03	701	5.8

Table 1 (Continued)

Urban/rural				
Urban	4016	83.29	9366	77.52
Rural	806	16.71	2717	22.48
Stove fuels				
Electricity	2471	51.25	6584	54.49
Natural Gas	1445	29.97	3753	31.06
LP Gas	178	3.68	528	4.37
Other fuels	727	15.09	1218	10.08
Separate freezer				
Yes	1542	31.99	3679	30.45
No	3280	68.01	8404	69.55
Dishwasher				
Yes	2554	52.96	7170	59.34
No	2268	47.04	4913	40.66
Dryer				
Yes	3552	73.67	9595	79.41
No	1270	26.33	2488	20.59
Outdoor lights left on all night				
Yes	1103	22.87	2805	23.21
No	3719	77.13	9278	76.79
Aquarium				
Yes	203	4.21	465	3.85
No	4619	95.79	11618	96.15
Computer				
Yes	2706	56.11	9173	75.91
No	2116	43.89	2910	24.09
Fax				
Yes	497	10.3	1083	8.97
No	4325	89.7	11000	91.03

Note: Race/ethnicity percentage totals exceed 100% due to the reason that 1.1% of respondents have chosen more than one race/ethnic category.

Table 2 Characteristics of ordinal and continuous variables in the models for appliance use for years 2001 and 2009

Cardinal and ordinal variables	Mean 2001	Mean 2009
Total number of rooms	7.48	5.92
Number of household members	2.56	2.57
Number of lights turned on more than 12 hours per day	0.44	0.45
Number of lights on between 4 hours and 12 hours/day	1.73	1.67
Number of lights turned on less than 4 hours per day	2.26	2.31
Number of color televisions per household	2.27	2.31
Age of the refrigerator	2.98	2.87

Regression analysis results and discussion

When modeling for the data for years 2001 and 2009 in order to avoid multicollinearity, the correlation between the dependent variable and various independent variables are kept under control. As mentioned earlier, the Pearson correlation coefficients between various variables employed in the models are under 0.50. In the RECS sample for the year 2001, the correlation coefficient between the variable for the "Use of dryer" and the variable "Total number of rooms in the building" is slightly larger and is 0.52. In both the samples for the rest of the independent variables the correlation coefficients are under the required level. This ensures that multicollinearity does not pose a problem in the modeling of household appliance's energy consumption using regression analysis (Hausfather et al., 2010).

Table 3 shows the results of the log-linear modeling of household energy consumption for the use of appliances for the years 2001 and 2009. The table includes details of parameter estimates and their exponentials. The procedure "proc surveyreg" in SAS software was used in both the regression models. The models using data for the years 2001 and 2009 accounts for 67.23% and 62.06% of the variation in the household energy consumption for space cooling.

The results from the table 3 show that the census divisions of New England, East North Central, West North Central, Mountain and Pacific are statistically significant in the model, whereas the divisions South Atlantic, East South Central, and West South Central are not statistically significant at 0.05 levels in the model for the year 2001 with reference to Middle Atlantic Census Division. Likewise, the coefficients of the Regression analysis for the year 2009 show that all Census Divisions in the model are statistically significant at 0.05 levels in the model. In the regression model for the year 2001 the divisions that are statistically significant have consumed lesser energy for appliances with reference to Middle Atlantic Division. The consumption of household energy for appliances in New England, East North Central, West North Central, Mountain and Pacific have decreased by 9.3%, 6.5%, 7.5%, 10.3% and 15.2% respectively with reference to the Middle Atlantic division.

However, the coefficients and their exponentials in the table 3 for the year 2009 shows a different picture of household energy consumption for appliance use for the Census Divisions. One important point here is all census divisions are statistically significant at 0.05 levels in the regression model. The energy consumption for census divisions of New England, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific are less by 7.3%, 7.8%, 12.9%, 9.7%, 6.9%, 8.3%, 18.4% and 16.9% respectively with reference to Middle Atlantic Census Division.

The results of regression models mentioned above show a clear variation in the household energy consumption for appliance use among census divisions for the year 2009 whereas the variations in household energy consumption for appliance use among various Census Divisions are not very clear for the year 2001 since the census divisions of South Atlantic, East South Central and West South Central are not statistically significant in the model. An earlier work on zip code level estimation of energy consumption of appliances for the year 2005 using the RECS data set has predicted significant variations among Census divisions in the use of energy for appliance use (Zeke Hausfather et al., 2010). However, the result from the current study on energy consumption for appliance use for year 2009 contradicts the conclusion that variation in household energy consumption are significant only among few Census Divisions in the United States while the results from the model for the year 2001 are in agreement with these results.

In the modeling of household appliances energy consumption, single-family detached housing type is taken as the reference to analyze the energy consumption of appliances in different type of housing units for the years 2001 and 2009. For instance, the preceding analysis shows that the in year 2001, every housing type other than mobile homes is statistically significant at the 0.05 level. The model for the year 2001 shows that single-family attached housing units used 11.5% less energy for appliances as compared to single-family detached units, whereas apartments with 2-4 units and apartments with 5 or more units used 10.7% and 21.2% less energy for appliances respectively.

The energy consumption among various housing types is not very different for the year 2009 in comparison to the year 2001. However, it can be seen from the model for the year 2009 that all different housing types in the model are statistically significant at 0.05 levels. Further it also shows that in the year 2009 mobile homes have consumed 5.9% more energy for appliances as compared to single-family detached housing units while single-family attached housing units, apartments with 4-5 units and apartments with more than 5 units have consumed 11.5%, 8.1%

and 22.3% less energy respectively with reference to single detached type housing units.

The models when analyzed for energy consumption for the appliance use indicate that there is increased energy consumption in apartments with 2-4 units, decreased energy consumption in apartments with 5 or more units and no change in the single family attached units when compared to the energy consumption of appliance in the single family detached units over the period 2001-2009.

The present study on household energy consumption of appliances see the emergence of mobile homes as a factor that contributed to change in household energy consumption of appliances along with the other housing units such as single family attached, single family detached, apartments with 4 to 5 units and apartments with more than 5 units. This result from the regression model for the year 2009 is different from results obtained in earlier studies (Jihoon Min et al., 2010 and Ewing and Rong, 2008) where only a few housing types but not all housing types accounted for the variation in household energy consumption for appliance use.

The household energy consumption for the use of appliances for different race/ethnic categories shows considerable differences for the year 2001 and 2009. For the year 2001, all race/ethnic categories are statistically significant in the regression model. In the year 2001 the race/ethnic category Black consumed 5.8% more energy on an average with reference to race/ethnic category White, whereas the race/ethnic categories Hispanics and others have used on an average 7.4% and 9.4% less energy as compared to race/ethnic category White.

Table 3 Regression coefficients and their exponential values for appliance use for years 2001 and 2009

Variables	Year 2001 N=4813		Year 2009 N=12064	
	Coefficients	Exp(Coeff)	Coefficients	Exp(Coeff)
Census Divisions				
New England Division	-0.097***	0.907	-0.076***	0.927
Middle Atlantic Division	Ref		Ref	
East North Central Division	-0.068**	0.935	-0.081**	0.922
West North Central Division	-0.078**	0.925	-0.138***	0.871
South Atlantic Division	-0.045	0.956	-0.102***	0.903
East South Central Division	0.002	1.002	-0.071*	0.931
West South Central Division	0.028	1.029	-0.087***	0.917
Mountain Division	-0.129***	0.897	-0.203***	0.816
Pacific Division	-0.164***	0.848	-0.185***	0.831
Housing Type				
Mobile Home	0.015	1.015	0.057**	1.059
Single-Family detached	Ref		Ref	
Single-Family attached	-0.122***	0.885	-0.122***	0.885
Apartments with 2-4 units	-0.123***	0.893	-0.084***	0.919
Apartments with 5 or more units	-0.238***	0.788	-0.252***	0.777
Race/ethnicity				
White	Ref		Ref	
Black	0.056**	1.058	0.057***	1.059
Hispanics	-0.077**	0.926	-0.028	0.972
Others	-0.098***	0.906	-0.014	0.986
Urban/rural				
Urban	Ref		Ref	
Rural	0.066***	1.068	0.088***	1.092
Stove fuels				
Electricity	Ref		Ref	
Natural Gas	0.306***	1.358	0.288***	1.334
LP Gas	0.181***	1.198	0.233***	1.263
Other fuels	0.155***	1.168	0.196***	1.217
Separate freezer				
Yes	0.241***	1.212	0.145***	1.156
No	Ref		Ref	

Table 3 (Continued)

Dishwasher				
Yes	0.076***	1.079	0.091***	1.095
No	Ref		Ref	
Dryer				
Yes	0.205***	1.229	0.250***	1.285
No	Ref		Ref	
Outdoor lights left on all night				
Yes	0.129***	1.138	0.081***	1.084
No	Ref		Ref	
Aquarium				
Yes	0.118***	1.126	0.154***	1.166
No	Ref		Ref	
Computer				
Yes	0.048***	1.049	0.082***	1.085
No	Ref		Ref	
Fax				
Yes	0.085***	1.089	0.083***	1.087
No	Ref		Ref	
Total number of rooms	0.042***	1.043	0.043***	1.044
Number of household members	0.199***	1.22	0.222***	1.248
Number of lights turned on more than 12 hours per day	0.032***	1.032	0.033***	1.033
Number of lights on between 4 hours and 12 hours per day	0.011**	1.011	0.009***	1.009
Number of lights turned on less than 4 hours per day	0.009**	1.009	0.009***	1.009
Number of color Televisions	0.048***	1.049	0.073***	1.076
Age of the refrigerator	0.028***	1.028	0.009**	1.013
Price of electricity/per 1000 BTU	-10.09***	0	-7.368***	0

Note: ***$p \leq 0.001$ **$p \leq 0.01$ *$p \leq 0.05$

In the model for the year 2009 the race/ethnic category Black alone is statistically significant in the regression model. Here too, this category used 5.9% more energy as compared to the White category. This clearly shows the change in the household energy consumption of appliances among various race/ethnic groups. The result also shows that, there is no change in the energy consumption for the use of appliances for race/ethnic category Black with reference to race/ethnic category White for the years 2001 and 2009.

Earlier studies have identified that race/ethnic differences as a contributor to the variations in the household energy consumption of appliances. A few earlier studies based on linear regression models in the study of household energy consumption found that price and income changes in the households affect the household energy consumption of various race/ethnic groups disproportionately (Ewing and Rong, 2008 andAdua et al., 2011). However, the current model for household energy consumption of appliances for the year 2009 shows only the race ethnic categories White and Black contribute to variation and the remaining race ethnic categories Hispanics and Other are not statistically significant in the regression model for the year 2009.

The results of regression models for the years 2001 and 2009 also indicate a clear divide in energy consumption of appliances among urban and rural homes. Rural homes are statistically significant in the regression model for the years 2001 and 2009. The modeling results show that rural homes have consumed about 6.8% and 9.2% more energy when compared to urban homes respectively for the years 2001 and 2009. In the year 2009 the rural homes consumed more energy for appliances when compared to the year 2001.

The role of urban/rural differentials in the household energy consumption of appliances is well documented in literature. In this thesis, the regression-based models explored for years 2001 and 2009 shows statistically significant variations in household energy consumption of appliances the urban and rural categories. This result is supported by a recent study in which the authors analyzed life style factors and the household energy consumption differences in urban and rural households driven by the differences in the use laundry, personal computers and air conditioners (Sanquist et al., 2011).

In the modeling of household energy consumption of appliances for the years 2001 and 2009, the category of stove fuels such as natural gas, propane/liquefied petroleum gas, and other stove fuels are significant in the regression models. Regression analysis for the year 2001 show that US households consumed 35.8%, 19.8%, and 15.5% more energy of natural gas, liquefied petroleum gas, and all other stove fuels respectively for appliances with reference to electricity for their stoves. For the year 2009, the consumption for stove fuels are 33.4%, 26.3%, and 21.7% more in the categories of natural gas, liquefied petroleum gas, and other fuels with reference to electricity. There is an increase in the use of liquefied petroleum gas and other fuels for stoves in the year 2009 as compared to the year 2001 whereas there is a slight decrease in the use of natural gas for stove in the year 2009 as compared to the year 2001.

Our analysis shows a sufficiently strong relationship between the energy consumption of appliances and different categories of energy sources such as electricity, natural gas, LP gas and other type of fuels used for stoves. This result is similar to a recent study on location and race differences in natural gas consumption (Auda et al., 2011) using fixed effect regression models upon RECS data sets for years 1993, 1997, 2001 and 2005. The energy consumption models predicted that the natural gas and other fuels as the major type of cooking fuels instead of electricity, while electricity and other fuels were statistically significant in three of the four models employed in the analysis.

The results from the models for years 2001 and 2009 show that washers and dryers contribute more to the appliances energy consumption when compared to households with no washer and dryer. In the year 2001 the households with dishwasher and dryer consumed 7.9% and 22.9% more energy than the households with no dishwasher and dryer while the corresponding increased consumptions are 9.5% and 28.5% for the year 2009. Households consumed more energy for the use of dishwasher and dryer during the year 2009 as compared to their energy consumption for the year 2001.

The energy consumption in the homes with aquariums, computers and faxes are no different from households equipped with dishwashers and dryers. For the year 2001, the households with aquariums, computers and faxes have consumed 12.6%, 4.9% and 8.9% more energy than the households with no aquariums, computers and faxes. The corresponding figures for the year 2009 are 16.6%, 8.5%, and 8.7% respectively for households with aquariums, computers and faxes. It can be seen from the models for years 2001 and 2009 that the energy consumption for the households with aquariums and computers have increased for the year 2009 as compared to their consumption in the year 2001 while for the households with faxes there is a slight decrease in the energy consumption for the year 2009 as compared to its consumption in the year 2001.

A similar trend in the role of color televisions in the household energy consumption for appliances can be seen in the models for the years 2001 and 2009. For the year 2001 the increase in the household energy consumption for appliance was 4.8% for one unit increase in color televisions while for the year 2009 this had increased to 7.6%. The regression models used here indicate that dishwasher, dryer, computer, fax, and color televisions as major category of appliances that contribute to the energy consumption of appliances in the households. These variables are highly significant in the model and also play an important role in contributing to the increased household appliances energy consumption. A recent study found that 65% of the U.S households use dishwashers that accounted for 3.2% of the total U.S. residential energy consumption in 2005 (Hoak et al., 2008). Similarly, more than 80% of the U.S households own clothes dryers consuming 4.2% residential primary energy in the United States (Building Energy Data book, 2010). In addition, 45% of the households in U.S. have more than three color televisions while 76% of households own at least one computer in the United States (RECS,

2009) resulting in an increased household energy consumption for appliances. These results are consistent with that obtained from the current models which confirm that dishwashers, dryers, computers and other electronic equipment are crucial factors for the increase in the household energy consumption in the United States.

Though, the appliances mentioned in the earlier paragraph are crucial in the energy consumed for household appliances, the importance of aquariums in the household energy consumption cannot be under stated. Aquariums are reef tanks and are set up as a sump and pump combination system. A typical aquarium requires over 100 gallons of water with power heads to increase the water movement. The tank also includes lighting and a mini AC unit for cooling (Sanchez et al, enduse.lbl.gov/info/ACEEE). Thus, aquarium consumes a considerable portion of household energy consumption. In the current model the variable aquarium is statistically significant and accounts for a considerable portion of the household appliance energy consumption.

The results of regression models for energy consumption for appliance use for the years 2001 and 2009 shows some consistency in the use of energy for lightings. The households that leave outdoor lights on all night consumed 13.8% and 8.4% more energy respectively for the years 2001 and 2009 than those households that do not leave outdoor lights on all night. The households that turned on lights more than 12 hours per day used 3.2% more energy per unit increase in the lights in the year 2001 while the corresponding figure is 3.3% for the year 2009. This shows that the increased energy consumption per unit increase in the lights have not changed much for the years 2009 and 2001. The models also show the repetition of this pattern for the households that turned on the lights between 4 hours and 12 hours per day. In these houses the consumption per unit increase in lights turns out to be 1.1% and 0.9% respectively for the years 2001 and 2009. The corresponding figures for households that turned on lights less than

4 hours a day are 0.9% for each of the years 2001 and 2009. The results altogether indicate that there are no significant changes in the household energy consumption for lights during the year 2001 and 2009.

The current study reveals that behavioral patterns, the number of light bulbs and type of light bulbs used in the households strongly influence the usage of energy for lightings. Our model includes various behavioral patterns in the use of lights and number of lights as variables. Even though these variables contribute less to the increased household energy consumption for the use of appliances individually, collectively they contribute more to the energy consumption for the use of appliances in the household. Further, all these variables are statistically significant in the regression models and confirm their strong association with the household energy consumption of appliances. The fact that US homes consume about 13% of all residential energy consumption (EIA, 2011) clearly endorses the results obtained from the current study that lighting is a significant factor in the household appliance energy consumption.

The total number of rooms in the household and number of household members are other important factors that contribute to energy consumption. The models energy consumption of appliance for the years 2001 and 2009 also show the change in energy consumption based the number of rooms in the household. In the year 2001 the increased consumption in energy for the appliance use for unit increase in the number of rooms is 4.3% whereas the corresponding increase in energy consumption for appliance use for the year 2009 stood at 4.4%, showing very little increase in the consumption of energy in the year 2009 in this category. These indicate the variation in household energy consumption of appliances per room remains nearly the same for years 2001 and 2009. Similarly, for the years 2001 and 2009 increase in one household member resulted in an increased consumption of 22% and 24.8% of energy for appliances, showing higher energy consumption for appliances in the year 2009.

The result from the current model is a clear indication that the total number of rooms in the house and number of household members are also important factors that contribute to the appliances energy consumption. In the current models on energy consumption for appliance use for years 2001 and 2009 show that both these variables are statistically significant in the models and contribute significantly to increased energy consumption of appliance. This positive linear relationship between the household energy consumption with increase in the physical size of the dwelling and number of members have been supported by many other earlier studies on household energy consumption (Hwang et al., 1994; Ritche et al., 1981; Vringer et al., 1995 and Ironmonger et al., 1995).

Refrigerators and freezers are another set of most common household appliances and they consume approximately 7.2% of an average household energy (Buildings Energy Data Book, 2010). In the current model too, separate freezer and age of the main refrigerator used in the household contribute to increased energy consumption in the households. Further, these variables are statistically significant in the model and play an important role in the household appliance energy consumption. Also, the results from models for years 2001 and 2009 show that households having separate freezer tend to consume more appliances than the households that do not have a separate freezer. In the year 2001 and 2009 the households with a separate freezer used 21.2% and 15.6% more energy respectively as compared to the households that do not have a separate freezer. The result from the current study is consistent with the result from an earlier study on estimation of zip code level energy consumption (Hausfather et al, 2010).

The results from models for years 2001 and 2009 show that the household energy consumption for use of appliances increase by 2.8% and 1.3% for the years 2001 and 2009 for one unit increase age of refrigerator. The results show decrease in the increased energy consumption for appliance use during 2009 for one unit increase in age of the refrigerator as compared to the increase of energy consumption for one unit increase in age of the refrigerator in the year 2001. The decrease might be partly due to the replacement of refrigerators in the households and partly due to the addition new homes in the 2009 survey. The result from this study that there is a decrease in energy efficiency of refrigerator over time is consistent with the results from earlier studies on product life cycle analysis of refrigerator (Deeg et al, 1998, wikes et al, 1999).

The influence of price on energy consumption is well documented in literature. As per the basic laws of economics, any increase in price always results in decrease in consumption. This is evident in the household energy consumption and the changes in price. The results from the study on California's energy crises during 2000 showed that about two thirds of the households have reduced their electricity consumption by 20% in response to steep rise in price (Reis et al, 2008). In the current study too, it is observed that the price of electricity has a negative relationship to household energy consumption of appliances, and comes out to be highly statistically significant in the model. However, the price of electricity does not explain the variation in the household energy consumption of appliances in the models for years 2001 and 2009.

Decomposition analysis results and discussion

Table 4 presents detailed results from the regression based decomposition analysis of household appliances energy consumption for the years 2001 and 2009. Table 4 also shows the proportion of changes in intercepts, means, coefficients and interaction of both means and coefficients for the years 2001 and 2009, computed separately for each independent variable. To interpret the changes in intercept, means, coefficients, interaction and their sum, Table 5 presents the exponential values of these proportions of changes for the period 2001-2009, computed separately for each independent variable. Then, the product of estimates of all variables is also shown in the last row separately for means, coefficients, their interactions and the sum.

Average household energy consumption for appliance use

From the linear regression models for years 2001 and 2009, the mean energy consumption for appliance is ($e^{10.075}$) =23,742 thousand BTUs and ($e^{10.133}$) =25,160 thousand BTUs per household respectively. This shows an increase of 6.0% in the energy consumption for appliances per household in the period 2001-2009. It is also evident that the share of energy consumption in the households for use of appliances keeps growing irrespective of Federal energy efficiency standards enacted on every major appliance. The outcome of the regression analysis for years 2001 and 2009 are similar to results by Department of Energy Administration using Residential Energy Consumption Survey (RECS, 2009 - Release date: March 28,2011).

Census Divisions and change in household energy consumption for use of appliances during 2001-2009.

Table 5 shows the exponentials of the proportion of changes due to intercepts, means, coefficients and interaction. Here, the mean is the ratio of households surveyed in the census division to the total number of households surveyed in the United States. The changes in the mean are the differences in those proportions of households surveyed for the years 2001 and 2009. Since there were no changes in the multistage area probability design used by RECS for years 2001 and 2009, there are no changes in the mean values in most of the Census Divisions. The New England, East North Central, West North Central, Mountain and Pacific Census divisions contribute very little or almost zero to the total change in the household energy consumption of appliances.

The results from decomposition procedure reveal that a large fraction of the contribution to the Census Divisions' total change in the household energy consumption of appliances between 2001 and 2009 is due to change in coefficients. However, the contribution to the total change in household energy consumption for appliance use over the period 2001-2009 is very little and suggests no variation in energy consumption among Census Divisions in the United States.

Housing types and change in the household energy consumption for appliance use during 2001-2009:

The different housing types in the models contributed very little to the household energy consumption of appliances during 2001-2009. Mobile homes are not statistically significant in one of the models for years 2001 and 2009. Of the statistically significant housing types in both models, e.g. single-attached home types, apartments with 2-4 units, and apartments with more than 5 units have contributed respectively by 0.5%, 0% and -0.1% to the total change in the household appliances energy consumption. In the case single-attached home types, the contribution to the mean value is 0.1% to the total change in consumption and for homes in apartments with 2-4 units there is no contribution to the coefficient of the total change in the consumption for appliance use. For homes in apartments with 5 or more units, the mean and coefficients have no contribution to the total change in the energy consumption. The cumulative contribution by housing types to total change in the household energy consumption for appliance use is very little, suggesting no variation during 2001-2009.

Table 4 Decomposition analysis results for appliance use: 2001-2009.

Variables	Proportion of changes due to			
	Mean	Coefficients	Interaction	Sum
New England Division	0.000	0.001	0.000	0.001
East North Central Division	0.000	-0.002	0.000	-0.002
West North Central Division	0.000	-0.004	0.000	-0.004
South Atlantic Division	0.000	-0.011	0.000	-0.011
East South Central Division	0.000	-0.005	0.000	-0.005
West South Central Division	0.000	-0.013	0.000	-0.013
Mountain Division	-0.001	-0.005	0.000	-0.006
Pacific Division	0.001	-0.003	0.000	-0.002
Mobile Home	0.000	0.003	0.000	0.003
Single-Family attached home	0.005	0.000	0.000	0.005
Home in apartments with 2-4 units	0.001	0.003	0.000	0.003
Home in apartments with 5 or more units	-0.002	-0.002	0.000	-0.005
Black	0.001	0.000	0.000	0.001
Hispanics	-0.006	0.003	0.004	0.001
Other	-0.001	0.004	0.001	0.004
Rural home	0.004	0.004	0.001	0.009
Stove fuel is natural gas	0.003	-0.005	0.000	-0.002
Stove fuel is LPG	0.001	0.002	0.000	0.004
Other types of fuels	-0.008	0.006	-0.002	-0.004
Total number of rooms in the household	-0.065	0.005	-0.001	-0.061
Household size	0.002	0.059	0.000	0.061
Number of lights turned on more than 12 hrs per day	0.000	0.000	0.000	0.001
Number of lights on between 4 hrs and 12 hrs per day	-0.001	-0.004	0.000	-0.004
Number of lights turned on less than 4 hrs per day	0.000	0.001	0.000	0.002
Number of outdoor lights left on all night	0.000	-0.011	0.000	-0.011
Separate freezer at home	-0.004	-0.030	0.001	-0.033
Dishwasher at home	0.005	0.007	0.001	0.013
Total number of rooms in the household	0.012	0.033	0.003	0.048
Number of color TVs at home	0.013	0.057	0.007	0.078
Aquarium at home	0.000	0.001	0.000	0.001
Computer at home	0.009	0.019	0.007	0.035
Fax machine at home	-0.001	0.000	0.000	-0.001
Age of the main refrigerator	-0.003	-0.045	0.002	-0.047
Square of household size	-0.002	-0.026	-0.001	-0.029
Price of electricity per 1000 BTU	-0.089	0.077	0.024	0.012
Sum of proportion of changes	-0.125	0.119	0.046	0.040

Table 5 Exponential values of proportion of changes for appliance use

Variables	Exponential values of changes due to			
	Mean	coefficients	Interaction	Sum
New England Division	1.000	1.001	1.000	1.001
East North Central Division	1.000	0.998	1.000	0.998
West North Central Division	1.000	0.996	1.000	0.996
South Atlantic Division	1.000	0.989	1.000	0.989
East South Central Division	1.000	0.995	1.000	0.995
West South Central Division	1.000	0.987	1.000	0.987
Mountain Division	0.999	0.995	1.000	0.994
Pacific Division	1.001	0.997	1.000	0.998
Mobile Home	1.000	1.003	1.000	1.003
Single-Family attached home	1.005	1.000	1.000	1.005
Home in apartments with 2-4 units	1.001	1.003	1.000	1.003
Home in apartments with 5 or more units	0.998	0.998	1.000	0.995
Black	1.001	1.000	1.000	1.001
Hispanics	0.994	1.003	1.004	1.001
Other	0.999	1.004	1.001	1.004
Rural home	1.004	1.004	1.001	1.009
Stove fuel is natural gas	1.003	0.995	1.000	0.998
Stove fuel is LPG	1.001	1.002	1.000	1.004
Other types of fuels	0.992	1.006	0.998	0.996
Total number of rooms in the household	0.937	1.005	0.999	0.941
Household size	1.002	1.060	1.000	1.062
Number of lights turned on more than 12 hrs per day	1.000	1.000	1.000	1.001
Number of lights on between 4 hrs and 12 hrs per day	0.999	0.996	1.000	0.996
Number of lights turned on less than 4 hrs per day	1.000	1.001	1.000	1.002
Number of outdoor lights left on all night	1.000	0.989	1.000	0.989
Separate freezer at home	0.996	0.970	1.001	0.968
Dishwasher at home	1.005	1.007	1.001	1.013
Total number of rooms in the household	1.012	1.034	1.003	1.049
Number of color TVs at home	1.013	1.059	1.007	1.081
Aquarium at home	1.000	1.001	1.000	1.001
Computer at home	1.010	1.019	1.007	1.036
Fax machine at home	0.999	1.000	1.000	0.999
Age of the main refrigerator	0.997	0.956	1.002	0.954
Square of household size	0.998	0.974	0.999	0.971
Price of electricity per 1000 BTU	0.915	1.080	1.024	1.013
Product of exponential values	0.883	1.127	1.047	1.041

Table 5 (continued)

Note (1) Difference in intercept for Log-linear models	0.0186
(2) Exponential value of difference in intercepts	1.0188

Race/ethnic differences and the change in household energy consumption for use of appliances during 2001-2009:

The results from decomposition in Table 5 show the contribution by various race/ethnic categories to the total change in the household appliances energy consumption between 2001 and 2009. Among the race/ethnic categories only the Black category is statistically significant in both the models for years 2001 and 2009. The contribution by the Black category for the total change in the household energy consumption during 2001-2009 is 0.1% and this contribution is due to changes in mean values in the models. The race/ethnic categories Hispanics and Other have contributed respectively by 0.1% and 0.4% to the total change in household appliances energy consumption. However, these race/ethnic groups are not statistically significant in the model for the year 2009. The small contribution by individual race/ethnic groups to total change in the household energy consumption of appliance and shows that there is no significant variation among various race/ethnic groups over the period 2001-2009.

Rural/urban differences and the change in household energy consumption for use of appliances during 2001-2009:

The decomposition analysis in Table 5 also shows that the rural homes do contribute considerably to the total change in the household energy consumption for appliances during 2001-2009. The contribution of rural homes is 0.9%, in which the mean values, regression coefficients and their interactions have no contribution. The results also indicate that in rural homes have consumed more energy when compared to urban homes over the period 2001-2009, thereby widening the gap appliances energy consumption.

Changes in fuel consumption and total change in the household energy consumption for appliance use:

The decomposition results in table 5 show various types of stove fuels and their contribution to the total change in appliances energy consumption during 2001-2009. Table 5 shows that all fuel types used in the households are statistically significant in both the models for years 2001 and 2009. Together, the results show that natural gas and other fuels contribute to the total change negatively while Propane/LPG have contributed positively to the total change in the household energy consumption for use of appliances during 2001-2009. During this period natural gas, Propane/LPG, and other fuels have contributed by -0.2%, 0.4%, and -0.4% respectively to the total change in appliances energy consumption. The contribution to the total change from water heating due to change in the mean for natural gas, Propane/LPG, and other types of fuels are respectively, 0.3%, 0.1%, and -0.8% while their contribution to the total change in energy consumption for appliance use by regression coefficients are -0.5%, 0.2%, and 0.6% respectively. The figures show partial contributions by change in means and regression coefficients of various types of fuels to the total change in household energy consumption for use of appliances. The results imply that there is a slight decrease in the use of stove fuels natural gas and other fuels and a marginal increase in the use of stove fuel Propane/LPG for the use of appliances over the period 2001-2009.

Total number of rooms in the household and the change in household energy consumption for appliance use during 2001-2009:

The role of the total number of rooms in the household and its energy consumption is well documented in the literature. Accordingly, it also plays a crucial role in contributing to the changes observed in the household energy consumption at the two different points of times. In the current study, the total number of rooms contributes -5.9% to the total change in energy consumption for appliance use during 2001-2009. Interestingly, about 6.3% came from the mean values in the models whereas only 0.5% is from change in the coefficients. Therefore, a large fraction in the total change in the household energy consumption for appliances due to the number of rooms is accounted by the model.

Household size and the change in household energy consumption for appliance use during 2001-2009:

Household size is another major factor that determines the household energy consumption. This contributes 6.2% to the total change in consumption. The change in mean values and coefficients of household size contribute by 0.2% and 6.0% respectively to the variation in the total change in the household energy consumption for appliance use during 2001-2009. This implies that a large fraction of variation in the total change in the appliances energy consumption remains unexplained.

Lights usage patterns and the change in household energy consumption for appliance use during 2001-2009:

In the analysis of this category, it is found that the number of lights turned on more than 12 hours per day has not contributed adequately to the total change in energy consumption. Number of lights turned on between 4 hours and 12 hours per day and number of lights turned on less than 12 hours per day contributed -0.4% and 0.2% to the total change in the household energy consumption of appliances and all these contributions are from coefficients in the model. In these lighting categories there is no or little change in the mean values indicating that energy consumption for lightings has remained the same in the years 2001and 2009 and that little variation in energy consumption for lighting is from coefficients, which remain unexplained in the model.

On the other hand the outdoor lights left switched on all night have contributed -1.1% to the energy consumption during 2001-2009. The model does not explain this contribution to the change in the household energy consumption for appliance use from the coefficients.

The role of Dishwasher and Dryer in the change in household energy consumption for appliance use during 2001-2009:

The decomposition results show that dishwasher and dryer contributed to a total change in the household energy consumption for appliance use by 1.3% and 4.9% during the period 2001-2009. Of these, contributions 0.5% and 1.2% are from a change in mean values while 0.7% and 3.4% are from change in coefficients in the models. These results from the current study indicate that most of the contribution by dishwasher and dryer to the total change in the household energy consumption is not explained.

The role of separate freezers and age of the refrigerator in the change in household energy consumption for appliance use during 2001-2009:

Freezers are appliances that need to be powered on the entire day, and therefore separate freezers consume considerable energy in the households. In the current study, freezers account for -3.2% variations in the change in the total energy consumption in between 2001 and 2009. The contribution from the mean values and coefficients are -0.4% and -3.0% respectively. This suggests that most of the variation is contributed by separate freezers to the total change in household energy consumption and remains unexplained in the model.

Refrigerator is another example of an appliance that consumes energy the entire day. In addition, the aging of refrigerator makes it energy inefficient resulting in more consumption of energy. In the present study this factor contributes to the total household appliances energy consumption by -4.6% and mostly (-4.4%) from the change in coefficients. This indicates that most of the contribution by the age of the refrigerator to the total change in the household energy consumption remains unexplained in the model.

The role of color televisions and computers in the change in household energy consumption for appliance use during 2001-2009:

The decomposition results in Table 5 indicate that color televisions and computers account for a considerable portion of variation in total change in household energy consumption during 2001-2009. Color televisions and computers account for 8.1% and 3.6% of variations in the total change in the household energy consumption of appliances. Of these, 1.3% and 1.0% are from change in the means while 5.9% and 1.9% are from change in coefficients of the models. The interaction of the mean and coefficients contributed very little to the variation to the total change in the household energy consumption of appliances in between 2001 and 2009. This increased consumption in 2009 as compared to 2001 is clear evidence for the shift in household energy consumption for appliance use from labor-saving to entertainment purposes.

Changes in energy consumption for appliance use due to changes in the price of electricity:

The decomposition analysis from Table 5 shows that changes in price of electricity contributes only a small fraction to the variation in the household energy consumption for appliance use during 2001-2009. 1.3% of the total variation comes from price changes while the contribution by mean, coefficients and interaction of mean and coefficients are -8.5%, 8.0%, and 2.4% respectively. The price of electricity exhibits opposing trends in their contribution when compared to the means and coefficients. The result indicates that most of the contribution by changes in price of electricity to the total change in the household energy consumption remains unexplained.

Emerging trends in the residential appliance use

Among the various demographic, building structure, economic, behavioral and equipment ownership variables shown in table 5, it is now possible to identify the variables responsible for the change in household energy consumption of appliance between the years 2001 and 2009. The summary of the change in household energy consumption over the period 2001-2009 can be stated as follows. For the year 2009 with reference to year 2001, a 1.9% increase due to intercepts and 11.7% decrease due to endowments or mean values, and 17.9% increase due to coefficients and interaction terms in the model for energy consumption. The variation due changes in mean values of the predictors result in 11.7% decrease in energy consumption for appliance use, and correspond to changes in various demographic, building structure, economic, behavioral and equipment ownership variables in the year 2009 as compared to the year 2001. The variation due to coefficients, in other words the unexplained variation of 17.9% increase in energy consumption for appliance use correspond to variation inherent to the system not accounted by the variables in the model.

The figures in table 5 show that single family attached housing type, households in the rural area, stove fuels natural gas and other type of fuels, total number of rooms in the household, ownership of separate freezer, dishwasher, dryer, color televisions, and computers, age of the main refrigerator, and price of the electricity contribute to the bulk of explained variation of 11.7% decrease in household energy consumption of appliances in the model. However, for the unexplained 12.7% increase in the household appliance energy consumption, there is contribution from every other variable in the model, whereas the bulk of the contribution is from the variables just mentioned.

It is pertinent to add that the results obtained from the regression based decomposition analysis are consistent with the eco-system theory on household energy consumption of appliance. The household energy consumption for appliance use, designated as energy consumption by human organisms, is influenced by rural area and electricity price that correspond to the natural environment. It can also be seen that the social environment indicated by the light and stove-usage behaviors also determines the energy consumption. It is also evident that the stock of appliances and the number of rooms in the household labeled as designed environment have played a crucial role in the household energy consumption for appliance use. In summary, it can be said the consumption of energy by the occupants in the household are influenced and determined by their natural environment, social environment and designed environment and is in agreement with the theoretical framework of the eco-system model for household energy consumption.

Tests of hypotheses discussion:

The results from the regression model for the year 2009 on household energy consumption for appliance use is the test for the research hypothesis that there are demographic, building structure, and behavioral factors associated with the household energy consumption of appliance in the United States. Since these factors are statistically significant variables in the model that determines the household energy consumption for appliance use and therefore rejects the null hypothesis. The research hypothesis that demographic, building structure, and behavioral factors are associated with household energy consumption of appliances therefore holds true.

Our model for household energy consumption of appliances for the year 2009 shows very clear statistically significant variation among various census divisions and housing types in United States. Among the race/ethnic categories only the Black category is statistically significant for the year 2009. The other major variables that determines the variation in household energy consumption for appliance use are urban/rural, stove fuels, separate freezer, dish washer, dryer, outdoor lights, aquarium, computer, fax, number of color televisions, number of rooms in the household, household size, age of the refrigerator, light bulb use patterns and electricity price.

The regression based decomposition analysis for the period 2001-2009 provides the test of research hypotheses for differences in household energy consumption for appliance use among census divisions, among race ethnic categories, among use of stove fuels, and due to all variables in the models. The decomposition analysis shows that less than 1% variation among census divisions during 2001-2009 rejecting the null hypothesis that there is no variation in the household energy consumption for appliance use among census divisions during 2001-2009. Similarly, the decomposition analysis shows a variation of less than 0.5% among race/ethnic categories, and less than 1% variation in the use of stove fuels. There is also 11.7% decrease in household energy consumption for appliance use due to all variables in the model and 18% overall increase in energy consumption due to unexplained variation in the model.

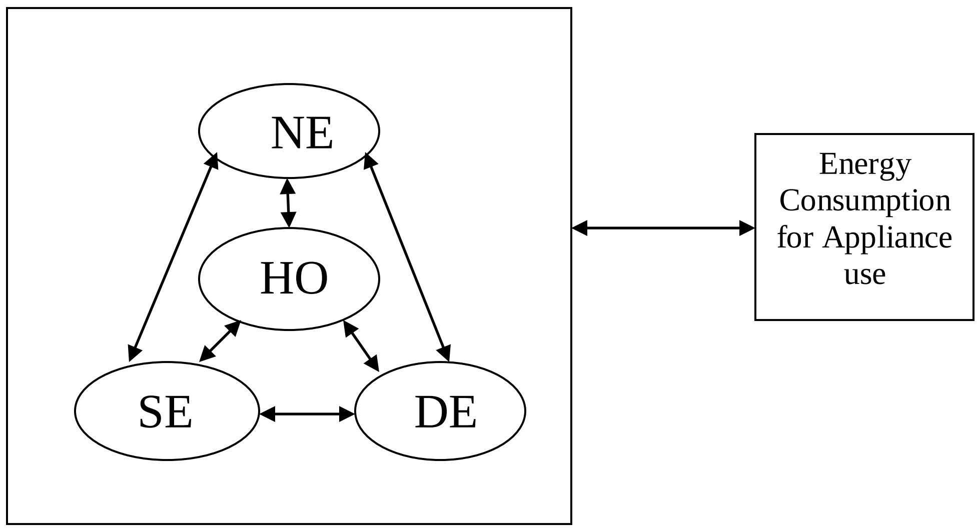

Figure 2 Eco-system model for household energy consumption for appliance use

Eco-system constituents for appliance use:

NE: Natural Environment – Geographical location, Electric energy price, and Urbanity

SE: Social Environment – Light bulb use patterns

DE: Designed Environment – Number of rooms in the household, and stock of household appliances including electronic items.

HO: Human Organism – Race/ethnicity and household size.

The unexplained variation in the model is the one that cannot be attributed to specific causes. This may be due to (1) change in the determinants of household energy consumption for appliance use over time during 2001-2009, (2) due to non-inclusion of small household appliances, (3) factors influencing household energy consumption for appliance use not captured in the survey (4) due to different brands of appliances showing variation in performance (5) due to unknown non-linear behavior of variables and (6) the unknown variation intrinsic to the system which cannot be captured in the statistical models.

Limitations of this study for household energy consumption for appliance use:

One main limitation of this study is that the models for the years 2001 and 2009 use the estimates of household appliances energy consumption as the outcome variable. This implies that any error in this outcome variable may have induced errors in the conclusions drawn from the model.

A second limitation is the increased use of electronic items in the households in United States since 2001. The RECS survey does not capture the exact number of such electronic items and the usage patterns of these items. This might result in erroneous conclusions to be drawn from the models.

The third limitation in this study is the small household appliances such as juice maker, electric grinders etc., in the households. Since RECS does not account such small appliances it might have caused errors in their estimation and consequently the results drawn from these models.

The RECS have used different definitions for some variables during 2001 and 2009. For example, the variable urban/rural has only two categories in the survey for the year 2001 while it has four categories for the year 2009. This divergent categorization of the variables in the survey for years 2001 and 2009 might distort the results from these models.

In the survey for the year 2009 there are multiple entries for mixed races spreading over to various race/ethnic categories. This might have induced some errors in the conclusions drawn from the model.

Finally, the determinants of household energy consumption for appliance use might have changed in the course of time since 2001 and the decomposition method has used same group of determinants for the years 2001 and 2009. This might have caused some errors in the conclusions drawn from the model.

CHAPTER FIVE: RESIDENTIAL ENERGY CONSUMPTION FOR SPACE HEATING

Introduction

In the United States, for decades more than 50% percentage of household energy was spent on heating and cooling of the residential space. However, findings from the recent RECS survey indicate that this trend in household energy consumption for space heating and space cooling is changing. The results from a recent study indicate that only 48% total household energy consumption was spent on heating and cooling during 2009 which is about 10% less than the energy consumed for same purpose in 1993. The Energy Information Administration (EIA) attributes this decrease in household energy consumption to the increased adoption of efficient heating and cooling equipment, improved building envelopes, more efficient windows and a population shift from cooler to warmer geographical regions (EIA, 2012). The present study on trends in household energy consumption for space heating and cooling during 2001-2009 is carried out in this context in an effort to determine the factors and the changes in these factors, which are ultimately responsible for such a change in household energy consumption.

Dependent variable in the model

In the modeling of household energy consumption for space heating using linear regression, the independent variable is the total amount of (estimated) energy used for heating in the years 2001 and 2009 in thousand BTUs. For the years 2001 and 2009, the estimated energy consumption for space heating in the survey is individually provided for electricity, fuel oil, LP gas, and kerosene and for natural gas. Thus the total energy for space heating for each household for the years 2001 and 2009 in thousand BTUs is:

Energy consumption for space heating for years 2001 and 2009

= Use of electricity for space heating + Use of natural gas for space heating

+ Use of fuel oil for space heating + Use of LPG for space heating

+ Use of kerosene for space heating

In modeling of household energy consumption for space heating using the method of linear regression, the dependent variable is non-zero continuous variable and the energy consumed is measured in thousand British Thermal Units (BTUs).

Independent variables and their measurements

In the regression models, in addition to variables that correspond to Census Divisions, race/ethnicity, urbanity, and housing types, there are also variables that correspond to the age of the householder, thermostat setting when someone is in home, thermostat setting when no one is in home, age of the heating equipment, the year in which the home was built, type of insulation, basement concrete, and household income. Since, the energy consumption for space heating in the household has no linear relationship with the age of the equipment, a variable that is proportional to the square of age of the equipment is included in the model. The relationship between energy consumption and price has been well documented (Acton and Mitchell, 1980 and Reis et al., 2008) and therefore can be readily incorporated in our work. For this reason the model also includes the average price of electricity paid by the household for space heating during the surveyed year, since households consume more of electricity as compared to other fuels for space heating. In the billing of electricity, block pricing is the practice and price of electricity has no linear relationship with household energy consumption. For this reason a variable that correspond to the square of the price of electricity is included in the model.

The variables in the model that correspond to the Census Divisions, race/ethnicity, housing type, urbanity, year in which the structure was built, age of heating equipment, type of the heating fuel used, respondent response of home insulation and basement concrete in the model are measured as categorical variables. The variables corresponding to the total number of rooms at home and income of the household in the previous 12-month period in the model are treated as the cardinal variables. The variables corresponding to the age of the householder, heating degree days, thermostat setting during the when someone is home, and thermostat setting when no one is home in the model is treated as continuous variables in the model. Further, the model does not include mobile homes and apartments with more than 5 housing units since their inclusion in the model resulted in a singular matrix, thus the method of decomposition cannot be used to assess the changes in household energy consumption for space heating during years 2001 and 2009.

Descriptive statistics

Table 6 present basic statistics for categorical, ordinal, cardinal and continuous variables that appear in the regression model for space heating. Table 7 shows a small decrease of 1.5 in the average number of rooms in the households from 2001 to 2009. There is a small decrease of 0.1 in the mean age of the main heating equipment in the households from 2001 to 2009 which indicate that during 2009 more households had heating equipment that is energy efficient. There is a small increase by 0.7 in the mean householders' age from 2001 to 2009. There are also increases in the mean values of thermostat setting when someone at home and when no one at home 0.72F and 5.54F respectively from 2001 to 2009. There is also an increase in mean heating degree days to 282.4 from 2001 to 2009. There is also a small increase in mean household income by 0.5 and increase in mean price of electricity in dollars per thousand BTU by 0.01 from 2001 to 2009.

Table 6 Characteristics of categorical variables in the models for space heating for years 2001 and 2009

Variables	Year 2001 N=4723		Year 2009 N=11534	
	Number	Percentage	Number	Percentage
Census Divisions				
New England	239	5.06	575	4.99
Middle Atlantic	653	13.82	1590	13.78
East North Central	764	16.18	1862	16.14
West North Central	330	6.98	841	7.29
South Atlantic	900	19.05	2255	19.55
East South Central	306	6.48	733	6.35
West South Central	530	11.22	1321	11.46
Mountain Division	300	6.35	817	7.09
Pacific Division	747	15.5	1802	14.91
Housing Type				
Mobile Home	303	6.42	701	6.08
Single-Family detached	1930	59.14	7379	63.98
Single-Family attached	474	10.04	689	5.97
Apartments/2-4 units	421	8.91	915	7.93
Apartments/5 or more	732	15.49	1850	16.04
Race/ethnicity				
White	3672	78.75	7892	68.42
Black	581	12.31	1587	13.76
Hispanics	245	5.2	1365	11.84
Others	224	5.98	690	5.98
Urban/rural				
Urban	3948	83.6	8925	77.38
Rural	775	16.4	2609	22.62
Heating fuels				
Electricity	1386	29.35	4033	34.96
Natural Gas	2653	56.16	5881	50.99
LP Gas	222	4.7	591	5.12
Fuel Oil	358	7.57	732	6.35
Other fuels	105	2.22	297	2.58

Table 6 (Continued)

Year home built	1174	24.87	1994	17.29
Year built is before 1950s	617	13.06	1373	11.9
Year built is in 1950s	603	12.77	1333	11.56
Year built is in 1960s	826	17.5	1833	15.9
Year built is in 1970s	812	17.19	1721	14.92
Year built is in 1980s	650	13.76	1686	14.62
Year built is in 1990s	41	0.9	1593	13.81
Year built is in 2000s				
Insulation Type	928	19.65	1923	16.67
Poorly insulated	1904	40.32	4483	38.87
Adequately insulated	1890	40.02	4140	44.46
Well insulated				
Concrete Floor	1307	27.67	4140	35.89
Yes	3416	72.33	7394	64.11
No				

Note: Race/ethnicity percentage totals exceed 100% due to the reason that 1.1% of respondents have chosen more than one race/ethnic category.

Table 7 Characteristics of ordinal and continuous variables for space heating in the models for years 2001 and 2009

Variables	Mean 2001	Mean 2009
Total number of rooms	7.50	5.98
Age of the main heating equipment	3.55	3.42
Householder’s age	49.72	50.43
Thermostat setting/ someone at home	68.99	69.71
Thermostat setting/ no one at home	60.86	66.40
Heating degree days to base 65	4002.71	4285.12
Household income	6.12	6.59
Electrical price in dollars/1000 BTU	0.03	0.04

Note: 1) Mean Household income between 6 and 7 indicates that the mean income is between $40,000.00 to $50,000.00.
2) Mean Age of the main heating equipment is between 3 and 4 indicates that the mean age is between 10 years to 19 years.

Table 6 shows the changes in the sample for categorical variables for the year 2009 as compared to the corresponding categorical variables in the year 2001. The percentage of households surveyed in the census divisions for the years 2001 and 2009 are nearly the same except for small changes. Among the housing types during 2009, an increase of 4.8% in the number of single-family detached households and 4.1% less single-family attached households were surveyed as compared to the year 2001. Among the race/ethnicity categories the number of households surveyed decreased by 10.3% for white, increased by 1.5% for black, and increased by 6.6% for Hispanics category from 2001 to 2009 while the percentage remained the same for Others category in both years. It can be inferred from the table that 6.2% more of rural households has been surveyed during 2009 as compared to the number of rural households surveyed in the year 2001.

Among the heating fuels there is an increase of 5.6% households that used electricity, a decrease of 5.2% households that used natural gas, and a decrease of 1.2% households that used fuel oil for space heating from 2001 to 2009. Further, there is a small increase in the percentage of households that used liquefied petroleum gas and other fuels for space heating in this period. There is a considerable variation among various categories in the year home built in these years, since more new homes have been included in the survey for the year 2009. Further, the households with concrete floor in the surveys had increased by 8.2% from 2001 to 2009. Among the respondents perception of home insulation categories the well-insulated category households increased in the surveys by 4.4% from 2001 to 2009.

Table 7 shows the mean of different variables employed in the regression models for year 2001 and 2009. The results show that the mean number of rooms in the household is decreased by 1.5 from 2001 to 2009 while mean age of the heating equipment decreased 0.1 from 2001 to 2009.

During 2001-2009 the mean householders' age and mean household income increased by 0.7 and 0.5 showing small change in mean values. The mean values for 'thermostat setting someone at home' and 'thermostat setting when no one at home' have increased by 0.7F and 7.2F from 2001 to 2009. The mean value for heating degree days in 2001 and 2009 are 4002.7 and 4285.1 respectively indicating an increase of 282.41 from 2001 to 2009. The mean value for price of the electricity also has increased very little per thousand BTU from 2001 to 2009.

Regression model results and discussion

Table 8 shows the outcome of the log-linear regression analysis of household energy consumption for space heating in 2001 and 2009. The table contains the coefficients and their exponentials and shows statistically significant variations among various census divisions. The models show that for year 2001 east south central division and west south central division are not statistically significant and in the year 2009 New England division and east south central division are not statistically significant. In both the years, all statistically significant divisions in the models have consumed less energy for space heating with reference to Middle Atlantic Division and is detailed in the following. East North Central Division used 16.6% less energy in the year 2001 and 18.8% less in the year 2009 with reference to Middle Atlantic Division, both of which indicate a decrease in energy consumption from 2001 to 2009 in this division. For the other divisions West North Central, South Atlantic, Mountain and Pacific, the consumptions for the year 2001 are less by 26.5%, 20.7%, 26.4%, and 18.3% respectively with reference to Middle Atlantic Division. Similarly for the year 2009 the energy consumption for space heating in divisions West North Central, South Atlantic, Mountain and pacific the consumptions for the year 2009 are less by 25.6%, 14.3%, 24.8%, and 17.4% respectively with reference to Middle Atlantic Division. The percentages for the year 2009 indicate an increase in energy consumption for space heating from 2001 to 2009. The results from this study on variations in household energy consumption for space heating among Census Divisions are similar to the results from an earlier study (Zeke Hausfather et al., 2010), in which the authors used RECS data from the year 2005 to estimate energy for space heating in small areas. Our results also agree with other studies on household energy consumption for space heating that have used regional variables to identify the geographical regions in terms of populations and climatic conditions and to estimate energy used for space heating (Ayudinalp et al., 2004 and Braun et al., 2010).

Table 8 also displays variations among different housing types with reference to single-family detached housing type for the years 2001 and 2009. The results show that mobile homes are not statistically significant in the regression models for years 2001 and 2009. Single-family attached units have consumed 5.9% and 10.7% less energy with reference to single detached type house types. In both years, apartments with 2 to 4 units do not show much variation in energy consumption for space heating. Apartments with 5 or more units have consumed 47.5% and 27.2% less energy in years 2001 and 2009 with reference to single-family detached homes. The variation in household energy consumption for space heating among various housing types observed here are similar to the ones in other studies on household energy consumption for space heating that used housing type as a dwelling attribute (Ayudinalp et al., 2004 and Braun et al., 2010).

The models for years 2001 and 2009 explain 77.1% and 76.1% of variation in the household energy consumption for space heating. The outcome of regression models listed in table 8 also indicates that there are race/ethnic differences in the household energy consumption for space heating. The models show that the race/ethnic category Black have consumed 28.4% and 14.2% more energy while Hispanics category have consumed 8.6% and 6.2% less energy as compared to reference category White in 2001 and 2009. These results are similar to results obtained from earlier studies on household energy consumption on location and race differences (Adua et al., 2011) and race/ethnic differences in space heating (Klein et al., 1984).

The regression models results from table 8 shows that the energy consumption in rural households is not statistically significant in 2009. In the year 2001 the rural households, besides being statistically significant in the model, showed an 8.2% increase in household energy consumption for space heating with reference to the urban households. However, this trend disappears in 2009 since the category rural is not statistically significant in the model for the year 2009. A few earlier studies on energy consumption for space heating that have controlled for household location in rural area have shown similar statistically significant result (Braun et al, 2010). However, in our work a mixed trend among the rural households has been observed in the energy consumption for space heating.

The regression models for household energy consumption for space heating for years 2001 and 2009 from table 8 indicate that in terms of BTUs multiple sources of energy for space heating are used, which are in the form of natural gas, liquefied petroleum gas, and fuel oil and electricity. During the year 2001 natural gas, liquefied petroleum gas, and fuel oil are consumed 2.68, 2.19 and 2.46 times respectively with reference to electricity in terms of BTUs for residential space heating while the consumption for the year 2009 are 3.6, 3.2, and 3.8 times respectively with reference to electricity for residential space heating. There is a 29.5% decrease in the use of other fuels for space heating by during 2001 and 41.5% decrease during 2009 with reference to residential electricity consumption for space heating. These results are similar earlier studies on space heating based on RECS data for the year 2005 (Hausfather et al., 2010). The results indicate that there is a shift from other types of miscellaneous fuels to electricity, natural gas, liquefied petroleum gas and fuel oil for household energy consumption for space heating in 2009. However, the results from the regression model does not indicate shift from one fuel to another among electricity, natural gas and liquefied petroleum gas for residential space heating. Details on Table 8 also indicate that old homes consume more energy for space heating with reference to homes built in 2000s. Homes built before 1950, in 1950s, in 1960s have consumed respectively 54.3%, 38.9%, and 31.5% more energy in 2001 while in the year 2009 the values for energy consumption are 21.9%, 5.3%, and 7.6% respectively. The homes built in 70s, 80s, and 90s do not show statistically significant variation in both models in household energy consumption with reference to homes built in 2000s. The vintage classes distinguished here serves as a proxy for insulation standard of the house (Schuler et al., 2000) and supposed to show variation among various vintage classes.

Table 8 Regression coefficients and their exponential values for space heating for years 2001 and 2009

Variables	Year 2001 N=4723		Year 2009 N=11534	
	Coefficients	Exp(Coeff)	Coefficients	Exp(Coeff)
Census Divisions				
New England Division	-0.074*	0.929	-0.049	0.953
Middle Atlantic Division	Ref		Ref	
East North Central Division	-0.182***	0.834	-0.208**	0.812
West North Central Division	-0.308***	0.735	-0.295***	0.744
South Atlantic Division	-0.232***	0.793	-0.154***	0.857
East South Central Division	0.064	1.067	-0.063	0.939
West South Central Division	0.04	1.041	-0.093**	0.911
Mountain Division	-0.306***	0.736	-0.285***	0.752
Pacific Division	-0.203***	0.817	-0.191***	0.826
Housing Type				
Mobile Home	0.054	1.055	0.016	1.016
Single-Family detached	Ref		Ref	
Single-Family attached	-0.061*	0.941	-0.112***	0.893
Apartments with 2-4 units	-0.102**	0.903	-0.098***	0.906
Apartments with 5 or more units	-0.644***	0.525	-0.317***	0.728
Race/ethnicity				
White	Ref		Ref	
Black	0.250***	1.284	0.133***	1.142
Hispanics	-0.090*	0.914	-0.064***	0.938
Others	-0.062	0.94	0.003	1.003
Urban/rural				
Urban	Ref		Ref	
Rural	0.079**	1.082	0.007	1.007
Space heating fuels				
Electricity	Ref		Ref	
Natural Gas	0.986***	2.68	1.275***	3.578
LP Gas	0.783***	2.188	1.160***	3.19
Fuel oil	0.899***	2.456	1.322***	3.752
Other fuels	-0.350**	0.705	-0.537***	0.585

Table 8 (Continued)

Year home built				
Year home built is before 1950	0.434***	1.543	0.198***	1.219
Year home built is before 1950s	0.328**	1.389	0.051*	1.053
Year home built is before 1960s	0.274**	1.315	0.073**	1.076
Year home built is before 1970s	0.259**	1.295	0.009	1.009
Year home built is before 1980s	0.133	0.897	-0.018	1.186
Year home built is before 1990s	0.094	1.099	-0.009	1.009
Year home built is after 2000s	Ref		Ref	
Home insulation				
Well insulated	Ref		Ref	
Adequately insulated	0.077***	1.08	0.170***	1.186
Poorly insulated	0.186***	1.204	0.183***	1.201
Concrete Floor				
Yes	-0.106***	0.899	-0.058***	0.943
No	Ref		Ref	
Total number of rooms in the housing unit	0.103***	1.109	0.050***	1.051
Age of the main heating equipment	-0.081*	0.922	-0.053*	0.948
Age of the Householder	0.003***	1.003	0.002***	1.002
Thermostat setting when someone at home	0.007***	1.007	0.009***	1.009
Thermostat setting when no one at home	0.001*	1.001	0	1.000
Heating degree days to base 65	0.000***	1.002	0.000***	1.001
Household income	0.011*	1.012	0.008**	1.008
Electrical price in dollars/1000 BTU	-5.515***	0.004	-3.993***	0.018

Note: ***$p \leq 0.001$ **$p \leq 0.01$ *$p \leq 0.05$

In contrast, our work shows statistical significance among a few vintage classes in the energy consumption for space heating and this is in agreement with results from both Rehdanz, 2007, and Braun et al., 2010.

Adequately insulated homes have consumed 8.0% and 18.6% more energy respectively in 2001 and 2009 while poorly insulated homes have consumed 20.4% and 20.1% more energy for space heating in 2001 and 2009 respectively with reference to well-insulated homes. This supports the result from an early study on residential space heating that concluded that 29% of variation in household energy consumption for space heating is attributed to building characteristics

(Sonderegger. R. C., 1978).

Concrete floor with low thermal conductivity is found to be useful for thermal insulation of buildings (Xu et al., 2000). This is corroborated by the details in table 8, which also indicate homes with concrete floor consume less energy for space heating. Examining Table 8, it can be seen that the homes with concrete floor have consumed 10.1% and 5.7% less energy as compared to the homes with no concrete floors in 2001 and 2009 respectively.

The total number of rooms of residence is an important dwelling characteristic and plays a crucial role in the household energy consumption for space heating. The total number of rooms can be used as a proxy for dwelling size, which is then used to estimate energy consumption for space heating (Sardianou, 2008). Following this argument, in the current study the total number of rooms is used instead of the dwelling size. The results from table 9 show that, the variable 'total number of rooms' is statistically significant in both the models for the years 2001 and 2009. The results also show that a unit increase results in 10.9% and 5.1% increased energy consumption respectively in the years 2001 and 2009. Our conclusions on the increased energy consumption per increase in number of rooms agree with that obtained elsewhere on energy consumption for space heating studies (Schuler et al., 2000 and Sardianou, 2008).

Regression modeling in Table 8 indicates 7.8% and 5.2% decrease in energy consumption in the households for space heating for a unit increase in the age of the heating equipment in 2001 and 2009 respectively. This is paradoxical since aging causes the heating equipment to be less energy efficient, resulting in increased energy consumption and the only reason can be the rebound effect as elaborated in the following. In new homes with latest equipment, the marginal cost for increasing the temperature to comfortable level is relatively low. This in turn results in occupants tending to consume more energy for space heating (Schuler et al., 2000). Besides, it should be noted that the relationship between the energy consumption and the age of heating equipment is quadratic, meaning that to begin with the equipment starts consuming less energy, and then flattens out, followed by an increased consumption of energy. However, the aging process and its relationship to energy consumption for various heating equipments need further investigation.

Age of the householder is a dominant factor in predicting the variation in the household energy consumption for space heating. Elderly people stay at home more than younger people and they most often prefer warm indoor temperature. This means that the older the householder higher the energy consumption for space heating. Regression model results from table 10 shows 0.3% and 0.2% increase in the household energy consumption for space heating for one year increase in age of the householder in 2001 and 2009 respectively. The result from this study is consistent with earlier findings on residential space heating (Rehdanz, 2006; Sandianou, 2008 and Schuller, 2000).

The level of thermal comfort or thermostat setting at home plays a crucial role in predicting the variation in the household energy consumption for space heating. Thermal comfort varies across households, depending upon the occupants' cultural background, age composition, and night/daytime preferences of temperatures (Lutzenhiser, 1993). In the current study the results from regression models from table 10 also indicate that the households tend to consume 0.7% and 0.9% more energy for space heating when someone is at home. This finding is consistent with earlier studies (Weihl et al., 1990). However, the variable "thermostat setting when nobody at home" does not contribute to variation in the household energy consumption for the years 2001 and 2009. Table 10 indicates that, though this factor is significant in the models, for every unit increase in heating degree days there is very little increase (0.2% and 0.1%) in the household energy consumption. This is again consistent with Hausfather et al., 2010.

Household income is a fundamental variable in predicting the variations in the household energy consumption for space heating. Past studies have predicted the association between income and energy consumption for space heating (Capper et al., 1982; Schuler et al., 2000 and Klein et al., 1987). The results from table 10 indicate that the household income has only a marginal effect on the household energy consumption for space heating. It can be inferred from the table that an increase in one unit income results in 1.2% and 0.8% increase in energy consumption. This is consistent with the analysis found in Schuler et al., 2000 and Sardianou et al., 2008.

The price of energy is another crucial factor in the prediction of variation in the household energy consumption (Isaskson, 1983). The relationship of energy price with energy consumption is negative and it is estimated that 1% price increase resulting in a 0.4% decrease in the fuel consumption for space heating (Scott, 1980). In the current study, it can be seen that the price of electricity bears a negative relationship with energy consumption for space heating. The price of electricity is statistically significant in the models for years 2001 and 2009, and has a huge impact on consumption of energy for space heating.

Results of decomposition analysis and discussion

Table 9 presents detailed results of the decomposition analysis of household energy consumption for space heating for the years 2001 and 2009 using log-linear models. It also shows the proportion of changes in intercept, endowments, coefficients and interaction for the year 2009 with reference to year 2001, computed separately for each independent variable. To interpret the and interaction, Table 10 presents the exponential values of the proportions of changes for the year 2009 with reference to the base year 2001, again computed separately for each independent variable. The product of estimated changes of all variables is presented in the last row of the table for the endowments, coefficients and interactions. These values will be used to predict the overall changes in the household energy consumption for space heating.

Change in average household energy consumption for space heating in 2009

The regression models for space heating for years 2001 and 2009 predicts the mean household energy consumption as ($e^{10.213}$) =27,297 thousand BTUs and ($e^{10.086}$) =24.015 thousand BTUs respectively. It is clear that this shows a decrease of 12% in the average energy consumption for space heating per household in 2009. These findings are supported by the estimates of Department of Energy Administration in 2013 that there is decreased energy consumption of about 10% from 1993 to 2009 for space heating and cooling in the households in the United States (RECS, 2009- Release date: March 7, 2013).

Table 9 Decomposition analysis results for space heating: 2001-2009

Variable	Proportion of changes due to			
	Mean	coefficients	Interaction	Sum
New England Division	0.000	0.001	0.000	0.001
East North Central Division	0.000	-0.004	0.000	-0.004
West North Central Division	-0.001	0.001	0.000	0.000
South Atlantic Division	-0.001	0.015	0.000	0.014
East South Central Division	0.000	-0.008	0.000	-0.008
West South Central Division	0.000	-0.015	0.000	-0.015
Mountain Division	-0.002	0.001	0.000	-0.001
Pacific Division	0.003	0.002	0.000	0.005
Mobile Home	0.000	-0.002	0.000	-0.002
Single-Family attached home	0.002	-0.005	0.002	-0.001
Home in apartments with 2-4 units	0.001	0.000	0.000	0.001
Home in apartments with 5 or more units	-0.004	0.051	0.002	0.049
Black	0.004	-0.014	-0.002	-0.013
Other	-0.001	0.003	0.001	0.003
Hispanics	-0.006	0.001	0.002	-0.003
Rural home	0.005	-0.012	-0.004	-0.011
Heating fuel is natural gas	-0.051	0.162	-0.015	0.096
Heating fuel is LPG	0.003	0.018	0.002	0.023
Heating fuel is fuel oil	-0.011	0.032	-0.005	0.016
Other types of fuels as heating fuel	-0.001	-0.004	-0.001	-0.006
Year the home built is before 1950s	-0.033	-0.059	0.018	-0.074
Year the home built is in 1950s	-0.004	-0.036	0.003	-0.037
Year the home built is in 1960s	-0.003	-0.026	0.002	-0.027
Year the home built is in 1970s	-0.004	-0.044	0.004	-0.044
Year the home built is in 1980s	-0.003	-0.026	0.003	-0.025
Year the home built is in 1990s	0.001	-0.012	-0.001	-0.012
Home is adequately insulated	-0.001	0.037	-0.001	0.035
Home is well insulated	0.046	-0.001	-0.001	0.045
Home has concrete floor	-0.009	0.013	0.004	0.008
Total number of rooms in the household	-0.158	-0.400	0.081	-0.477
Age of the heating equipment	0.011	0.098	-0.004	0.105
Square of the age of heating equipment	-0.013	-0.091	0.005	-0.098
Householders' age	0.002	-0.089	-0.001	-0.088

Table 9 (Continued)

Thermostat setting when someone at home	0.005	0.180	0.002	0.187
Thermostat setting when no one at home	0.007	-0.055	-0.005	-0.053
Heating degree days to base 65	0.073	-0.221	-0.016	-0.164
Household income	0.005	-0.022	-0.002	-0.019
Price of electricity per 1000 BTU	-0.048	0.043	0.013	0.008
Sum of proportion of changes	-0.185	-0.487	0.088	-0.584

Change in household energy consumption for space heating during 2001- 2009 among Census Divisions:

Table 10 also shows the contributions made by various Census Divisions to the total change in the household energy consumption for space heating. East North Central, West North Central, South Atlantic, Mountain, and Pacific Census Divisions have contributed respectively, -0.4%, 0%, 1.4%, -0.1% and 0.5% to the total change in the household energy consumption for space heating in between 2001 and 2009. These contributions are partly from the mean values and the rest are from coefficients. The contribution by various Census Divisions is very small to the total change in the energy consumption for space heating in between 2001 and 2009, indicating that over this period the energy consumption pattern among Census Divisions remain unchanged.

Various housing types and Change in household energy consumption for space heating during 2001- 2009:

The contributions by single attached housing units, homes in apartments with 2 to 4 units, and homes in apartments with 5 or more units are -0.1%, 0.1% and 5.0% respectively.

Table 10 Exponential values of proportion of changes for space heating

Variables	Exponential values of proportion of changes of			
	Mean	coefficients	Interaction	Sum
New England Division	1.000	1.001	1.000	1.001
East North Central Division	1.000	0.996	1.000	0.996
West North Central Division	0.999	1.001	1.000	1.000
South Atlantic Division	0.999	1.015	1.000	1.014
East South Central Division	1.000	0.992	1.000	0.992
West South Central Division	1.000	0.985	1.000	0.985
Mountain Division	0.998	1.001	1.000	0.999
Pacific Division	1.003	1.002	1.000	1.005
Mobile Home	1.000	0.998	1.000	0.998
Single-Family attached home	1.002	0.995	1.002	0.999
Home in apartments with 2-4 units	1.001	1.000	1.000	1.001
Home in apartments with 5 or more units	0.996	1.052	1.002	1.050
Black	1.004	0.986	0.998	0.988
Other	0.999	1.003	1.001	1.003
Hispanics	0.994	1.001	1.002	0.997
Rural home	1.005	0.988	0.996	0.989
Heating fuel is natural gas	0.950	1.176	0.985	1.101
Heating fuel is LPG	1.003	1.018	1.002	1.023
Heating fuel is fuel oil	0.989	1.033	0.995	1.016
Other types of fuels as heating fuel	0.999	0.996	0.999	0.994
Year the home built is before 1950s	0.968	0.943	1.018	0.929
Year the home built is in 1950s	0.996	0.964	1.003	0.964
Year the home built is in 1960s	0.997	0.975	1.002	0.974
Year the home built is in 1970s	0.996	0.957	1.004	0.957
Year the home built is in 1980s	0.997	0.974	1.003	0.975
Year the home built is in 1990s	1.001	0.988	0.999	0.988
Home is adequately insulated	0.999	1.038	0.999	1.036
Home is well insulated	1.047	0.999	0.999	1.046
Home has concrete floor	0.991	1.013	1.004	1.008
Total number of rooms in the household	0.854	0.670	1.085	0.621
Age of the heating equipment	1.011	1.103	0.996	1.111
Square of the age of heating equipment	0.987	0.913	1.005	0.907
Householders' age	1.002	0.915	0.999	0.916

Table 10 (Continued)

Thermostat setting when someone at home	1.005	1.198	1.002	1.206
Thermostat setting when no one at home	1.007	0.946	0.995	0.948
Heating degree days to base 65	1.076	0.801	0.985	0.849
Household income	1.005	0.978	0.998	0.981
Price of electricity per 1000 BTU	0.953	1.044	1.013	1.008
Product of exponential values	0.831	0.614	1.092	0.558

Note: (1) Difference in intercepts for Log-linear models for years 2001 and 2009 0.4561

(2) Exponential value of difference in intercepts for years 2001 and 2009 1.5778

Of these, contributions by the means are 0.2%, 0.1% and -0.4% and by the coefficients are -0.5%, 0%, 5.2% respectively. The contribution by interaction terms to the total contribution by each apartment type is very negligible. This indicates that the homes in 5 or more units are the major contributor to the total change in energy consumption. However, the variation contributed by homes in 5 or more units is unexplained since only coefficients contributed to the variation. The mobile homes, besides having little effect on the total change in energy consumption, are not significant in the models.

Race/ethnic differences and change in household energy consumption for space heating over the period 2001- 2009:

Among the various race/ethnic categories in the model, Blacks and Hispanics have contributed by -1.2% and -0.3% to the total change in consumption. Of these, the contributions by the means are 0.4% and -0.6% and by the coefficients are -1.4% and 0.1%. This implies that most of the contribution by this race/ethnic category is unexplained. The race/ethnic category ‘Other’ is not statistically significant in the model.

Rural /urban differences and change in household energy consumption for space heating:

Table 10 shows the contribution by rural homes to the total change in the household energy consumption. Rural homes contribute by 1.1% to the total change in the household energy consumption for space heating during the period 2001-2009 out of which 1.2% is contributed by coefficients. This shows that a large part of its contribution to changes in the household energy consumption is unexplained. However, a variable rural home is not statistically significant in the model for the year 2009. Therefore, the urban/rural differences do not appear to play a significant role in variations noticed.

Heating fuels and total change in household energy consumption for space heating during 2001-2009:

The decomposition results from table 10 show contribution by various heating fuels to total change in energy consumption to heat spaces. The contribution by natural gas, propane/LPG, fuel oil and other fuels are respectively 10.1%, 2.3%, 1.6% and -0.6%. The contributing components for natural gas are -5.0% from the means, 17.6% from the coefficients and -1.5% from the interaction of mean and coefficients. Therefore, most of its contribution to the total change in household energy consumption is unexplained. Similarly, for propane/LPG, the contributions are 0.3% from the means, 1.8% from the coefficients and 0.2% from the interaction of means and coefficients. Here too, most of the contribution to total change in energy consumption for heating is from coefficients. In case of fuel oil -1.1%, 3.3%, and -0.5% are respectively from the means, coefficients and interaction terms whereas for other fuel types -0.1%, -0.4% and -0.1% are from mean, coefficient, and interaction terms. In all these fuel types most of their contribution to total change in energy consumption for space heating are from coefficients indicating that their contribution did not explain the variation in the total change and outweighs their contribution to the accounted variation in change in energy consumption for space heating during 2001-2009.

Vintage categories and total change in the household energy consumption for space heating during 2001-2009:

The results from table 10 show the contribution of various vintage categories to the total change in the household energy consumption for space heating. The homes built before the 50s, in the 50s, and in the 60s, have contributed by -7.1%, -3.6%, and -2.6% to the total change in the household energy consumption. The contribution for homes built before 50s are -3.2%, -5.7%, and 1.8% are respectively from the mean, coefficient and interaction terms. The contribution for homes built in the 50s are 0.3%, 1.8%, and 0.2% are respectively from the mean, coefficient and interaction terms while for homes built in 60s the numbers are -0.3%, -2.5%, 0.3%. These results indicate that every factor in the component analysis have contributed considerably to both the explained and unexplained variation in the total change in the household energy consumption for space heating. The homes built in the 70s is not statistically significant in the model for the year 2009 while homes built in the 80s and 90s are not significant in both the models for years 2001 and 2009.

Types of insulation and change in household energy consumption for space heating during 2001-2009:

Table 10 displays the components for the variables moderate insulation and poor insulation categories in the households. The homes with moderate and poor insulation have contributed 3.6% and 4.6% to the total change. In case of the homes with moderate insulation most contribution is from coefficients while in the case of homes with poor insulation most of its contribution is from mean values. Therefore, from this category the contributions for total change in the household energy consumption are from both the mean and coefficient.

The effect of concrete floor and total number of rooms on total change in the household energy consumption:

Table 10 shows that concrete floors in the households have contributed by 0.8% to the total change. The components of this contribution from the mean, coefficient and interaction terms are -0.9%, 1.3%, and 0.4% respectively indicating that the contribution is unexplained in the model. Table 10 shows that the variable total number of rooms accounts for a considerable amount of the total change in the household energy consumption for space heating. This variable's contribution to total change is -37.9% and the contribution by mean, coefficient and interaction terms are respectively, -14.6%, -33.0% and 8.5%. Here, each component of the models has contributed considerably to the total change in the household energy consumption for space heating during 2001-2009.

The effect of age of the householder and household income on total variation in the household energy consumption for space heating during 2001-2009:

Table 10 shows the contribution of the age of the householder to the total variation in household energy consumption for space heating. This variable contributed -8.4% to the total variation in the energy consumption. As the components of the analysis reveal, the contribution is made up of 0.2% from mean, -8.5% from coefficients, and -0.1% from interaction terms. This indicates that most of the contribution from the variable age of the householder to total variation in energy consumption is from coefficients and is unexplained in the model.

Table 10 also shows the contribution by household income to the total variation in household energy consumption for space heating. The contribution by household income to the total variation is -1.9% and the contribution by components to this are 0.5% by mean, -2.2% by coefficients, and -0.2% by interaction terms. These components suggest that the major contribution by household income to total variation in energy consumption from coefficients and remains unexplained.

Age of the equipment and the variation in total energy consumption for space heating during 2001-2009:

Table 10 shows the contribution of age of the equipment to the total variation in household energy consumption for space heating along with its components. It has a contribution of 11.1% to the total variation in the household energy consumption between 2001 and 2009. The components mean, coefficient and interaction terms have contributed by 1.1%, 10.3% and -0.4% to this 11.1% contribution by age of the equipment to the total variation in household energy consumption for heating. The components indicate that coefficients make up the majority of the 11.1% contribution and remain unexplained in the model.

Thermostat setting behavior and variation in household energy consumption for space heating in between 2001 and 2009:

The behavior of "thermostat setting when someone at home" has contributed by 20.6% to the total change in the household energy consumption for space heating. The components mean, coefficient and interaction terms make up this 20.6% contribution by 0.5%, 19.8% and 0.2%. The figures indicate that coefficients contribute to most of this variation and remain unexplained in the model.

Thermostat setting when nobody at home has contributed by -5.2% to the total variation. Of this, the contribution of mean, coefficients and interaction terms are respectively 0.7%, -5.4% and -0.5%. The components show that most of the contribution by the variable thermostat setting to the total variation is from coefficients and is unexplained in the model.

Heating degree days and the variation in total household energy consumption for space heating during 2001-2009:

The variable representing 'heating degree days in a year' is a major contributor to total variation and it contributes by -15.1% to the total variation. The components mean, coefficient, and interaction terms provide 7.6%, -19.9% and -1.5% respectively to make up this -15.1% contribution by heating degree days. However, most part of this contribution is by coefficients and that remains unexplained in the model.

Price of electricity and variation in household energy consumption for space heating during 2001-2009:

The unit price of electricity paid by the household has contributed by 0.8% to the total variation. The components means, coefficients and interaction terms have contributed respectively by -4.7%, 4.4% and 1.3% to this 0.8% contribution. In this case both mean and coefficients have contributed almost equally and the contribution is partly explained and partly unexplained in the model.

The determinants and trends in household energy consumption for space heating:

The component analysis allows one to assess the major factors responsible for the variation in household energy consumption for space heating. Homes in the apartments with 5 or more units, the race/ethnic category Black, natural gas, propane/LPG , fuel oil, vintage building categories built before 50s, built in 50s, and built in 60s, insulation categories, total number of rooms, age of the heating equipment, age of the householder, thermostat settings when someone at home and when no one at home, number of heating degree days, and household income emerge as the major factors in the variation in household energy consumption for space heating during 2001-2009. Besides, the regression models indicate a very strong association between these variables and household energy consumption for space heating. A threefold increase in the use of other fuels as compared to the use of electricity for space heating in the model for the year 2009 is evident. Additionally, a twofold increase of use of the other fuels as compared to use of electricity is evident in the model for year 2001. These factors account for the variation in the consumption and also determine the requirement of energy. Therefore, these factors deserve close attention and through analysis in the household energy consumption for space heating.

We also note that results obtained from the regression based decomposition analysis are consistent with the eco-system theory on household energy consumption for space heating. In other words, the household energy consumption for space heating, designated as consumption by Human Organisms, varies with their race/ethnicity, income and age and greatly influenced by heating degree days that correspond to Natural Environment. It can also be seen that the energy consumption for space heating is also related to the Social Environment indicated by the thermostat setting behavior of the householder. In this case, the Designed Environment that includes the number of rooms in the household, age of the building structure, age of heating equipment, and insulation have played a crucial role in the household energy consumption for space heating. In summary, it can be said the consumption of energy for space heating by the occupants, the Human Organism, in the household interactively depends on their Natural

Environment, Social Environment and Designed Environment which is in accordance with the theoretical framework provided by eco-system model for household energy consumption.

Discussion on the tests of hypotheses:

Based on the results of the regression model for the year 2009 on household energy consumption for space heating, we test the research hypothesis that there is demographic, building structure, and behavioral factors associated with household energy consumption for space heating in the United States. This can be done by checking the statistical significance of variables in the model for the year 2009 that determine the household energy consumption for space heating. This allows one to reject the null hypothesis and accept the alternative.

The current model for household energy consumption for space heating shows statistically significant variation in energy consumption for space heating among most of the census divisions except for New England Division and East South Central Division. Similarly among housing types in the variation in household energy consumption for space heating is substantial except for mobile homes. Among the race/ethnic categories the variation in household energy consumption for space heating occurs for the Black and Hispanics categories in the model for the year 2009. The other major variables that determine the variation in household energy consumption for space heating are fuels, building vintage categories, home insulation categories, floor categories, total number of rooms, age of the main heating equipment, age of the householder, thermostat use patterns, heating degree days, household income and electric energy price.

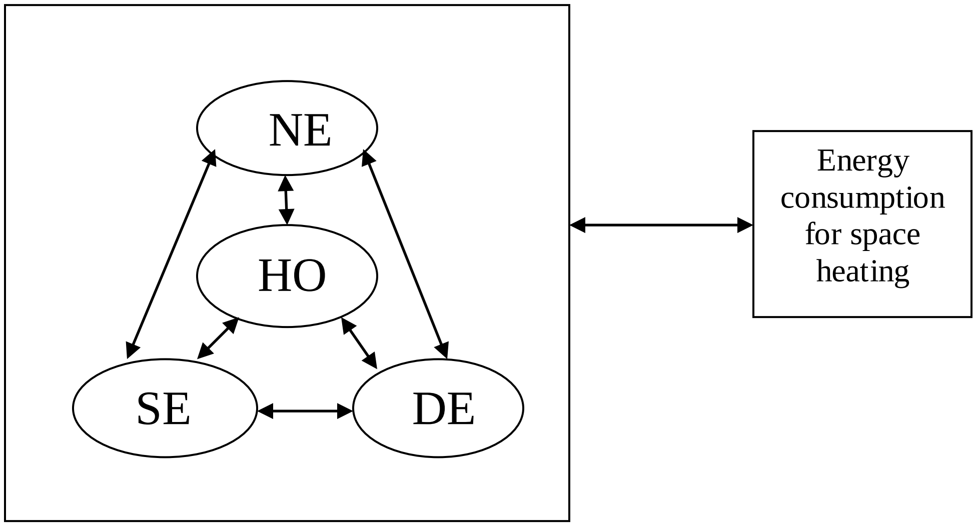

Figure 3 Eco-system model for household energy consumption for space heating

Eco-system constituents for space heating:

NE: Natural Environment – Geographical location, heating degree days, Electric energy price, and Urbanity

SE: Social Environment – Thermostat setting preferences

DE: Designed Environment – Housing type, number of rooms in the household, heating equipment, floor type, insulation type, space heating fuel, and building vintage categories.

HO: Human Organism – Race/ethnicity, householders' age, and household income.

The results from the regression based decomposition analysis provide material for the test of research hypotheses for differences in household energy consumption for space heating among census divisions, among race ethnic categories, among use of stove fuels, and due to all variables in the models. The decomposition analysis indicates there is a variation, less than 1.5% among census divisions during 2001-2009 rejecting the null hypothesis that there is no variation in the household energy consumption for space heating during 2001-2009. Similarly, the decomposition analysis shows a decrease of 1.2% in household energy consumption for space heating with race/ethnic category black and among space heating fuels there is increase in the use of natural gas, fuel oil, and liquefied petroleum gas by 10.1%, 2.3%, and 1.6% respectively while there is a decrease in the use of other fuels by 0.6%. The variation in household energy consumption for space heating due to all variables in the model is 16.9% decrease due to mean values and 33% decrease due to unexplained variation.

The unexplained variation in the model is the one that cannot be attributed to specific causes. The unexplained variation in the decomposition analysis may be due to (1) change in the determinants of household energy consumption for space heating over time since 2001, (2) due vintage categories not adequately capturing the variation in household energy consumption for space heating (3) inadequate measure of building insulation types (4) due to different brands of space heating equipment showing variation in performance (5) due to unknown non-linear behavior of variables in the models and (6) the unknown variation intrinsic to the system cannot be captured in the statistical models.

Limitations of this study for household energy consumption for space heating:

An important limitation of this study is that the models for years 2001 and 2009 use the estimated values of household energy consumption for space heating as the outcome variable. This mean any error in this outcome variable may have induced errors in the conclusions drawn from the model.

The RECS have used different definitions for some variables during 2001 and 2009. For example, the variable urban/rural has only two categories in the survey for the year 2001 while it has four categories for the year 2009. Such different categorization in the survey for years 2001 and 2009 in variables might have distorted the results from these models.

In the survey for the year 2009 there are multiple entries for mixed races spreading over to various race/ethnic categories. This might have induced some errors in the conclusions drawn from the model.

Finally, the determinants of household energy consumption for space heating might have changed in the course of time since 2001 and the decomposition method has used same group of determinants for the years 2001 and 2009. This might have caused some errors in the conclusions drawn from the model.

CHAPTER SIX: RESIDENTIAL ENERGY CONSUMPTION FOR SPACE COOLING

Dependent variable in the model

In the modeling of household energy consumption for space cooling using linear regression, the independent variable is the total amount of (estimated) energy used in the household for space cooling for the years 2001 and 2009 in thousand BTUs. For these years, the energy estimates for air conditioning in RECS is provided by the electricity consumption in thousand BTUs. Thus the total energy consumption for space cooling is:

Energy consumption for space cooling = Use of electricity for air conditioning

In the linear regression modeling of the household energy consumption for space cooling the dependent variable is used as non-zero continuous variable and the energy consumption is measured in thousands of BTUs.

Independent variables and their measurements

In the regression models, in addition to the variables that correspond to Census Divisions, race/ethnicity, urbanity, and housing types, also have variables that corresponds to the window/wall air conditioning units, total number of rooms in the building, age of the householder, number of household members, number of children in the household, number of senior members in the household, cooling degree days, and household income. The relationship between energy consumption and price has been well documented (Acton et al., 1980 and Reis et al., 2008) and for this reason the model also includes the average price of electricity paid by the consumer for space cooling during the surveyed year.

The variables in the model corresponding to Census Divisions, race/ethnicity, housing type, urbanity, and presence window/wall air conditioning units are measured as categorical variables. The cardinal variables comprise of total number of rooms at home, number of household members, number of children in the household, number of seniors in the household, and income of the household in the previous 12-month period. The variables corresponding to the age of the householder, cooling degree days and electricity price are treated as continuous variables in the regression models for years 2001 and 2009.

Descriptive statistics

Table 11 presents the distribution of the 2001 and 2009 sample across all variables used in this regression analysis. The 2001 and 2009 samples reveal a decrease in household energy consumption for space cooling. This is more than 25% decrease in household energy consumption for cooling purposes.

The samples also indicate no considerable changes in the number of households surveyed among census divisions. In Mountain and Pacific census divisions about 2% more households are surveyed in 2009 as compared to 2001. Similarly among the various housing types in 2009 about 4% more of single family detached type homes, 4% less of single family attached homes, and 1% more of homes in apartments with 5 or more units are surveyed with reference to the corresponding types of households surveyed in the year 2001.

Table 11 Characteristics of categorical variables in the models for space cooling for years 2001 and 2009

Variables	Year 2001 N=3464		Year 2009 N=9940	
	Number	Percentage	Number	Percentage
Census Divisions				
New England Division	135	3.9	413	4.15
Middle Atlantic Division	475	13.7	1331	13.39
East North Central Division	575	16.61	1589	15.99
West North Central Division	289	8.34	783	7.87
South Atlantic Division	816	23.55	2245	22.58
East South Central Division	273	7.89	730	7.34
West South Central Division	491	14.18	1306	13.14
Mountain Division	138	3.97	598	6.01
Pacific Division	272	7.86	945	9.5
Housing Type				
Mobile Home	221	6.37	614	6.18
Single-Family detached	2114	61.02	6464	65.03
Single-Family attached	354	10.23	592	5.96
Apartments with 2-4 units	271	7.82	662	6.66
Apartments with 5 or more units	504	14.56	1608	16.17
Race/ethnicity				
White	2749	79.36	7892	69.29
Black	409	11.81	1587	13.74
Hispanics	147	4.24	1365	11.47
Others	159	4.58	690	5.5
Urban/rural				
Urban	2896	83.6	8925	76.55
Rural	568	16.4	2609	23.45
Type of air conditioning equipment				
Central air conditioning	1464	71.13	4033	76.55
Window/wall type air conditioning	1000	28.87	5881	23.45

Note: Race/ethnicity percentage totals exceed 100% due to the reason that 1.1% of respondents have chosen more than one race/ethnic category.

Table 12 Characteristics of ordinal and continuous variables for space cooling in the models for years 2001 and 2009

Variables	Mean 2001	Mean 2009
Energy consumption for cooling	4982	3355
Total number of rooms	7.68	8.01
Householders' age	49.86	50.36
Number of household members	2.55	2.59
Number of children	0.47	0.45
Number of Senior citizens	0.35	0.33
Cooling degree days to base 65	1577.57	1506.12
Household income	6.32	6.67
Electrical price	0.03	0.04

Note: 1) Mean Household income between 6 and 7 indicates that the mean income is between $40,000.00 and $50,000.00.
2) Mean Age of the main heating equipment is between 3 and 4 indicates that the mean age is between 10 years to 19 years.

The samples further reveals that among various race/ethnic categories, in 2009 about 9% white households, about 2% more of black households, and about 6% more of Hispanics households are surveyed as compared to the corresponding households surveyed in 2001. Likewise, among rural/urban categories about 7% more of rural households are surveyed in 2009 compared to year 2001. It can also be seen from the samples that there is about 5% more households that have central air conditioning at homes in 2009 as compared to the year 2001.

Table 12 shows that the samples do not show significance differences in the mean values of remaining independent variables in the model. However, there is a decrease of 71 cooling degree days in its mean value in the year 2009 as compared to the mean value of cooling degree days in the year 2001. It also shows a decrease in energy consumption by 1627 thousand BTUs from 2001 to 2009.

Regression model results and discussion

Table 13 shows the results of regression models of household energy consumption for space cooling for the two years. The table also details the coefficients and their exponentials for both years. Before further discussions, we note that during variable selection it was found that the age of the householder and number of senior citizens in the household are highly correlated with a Pearson correlation coefficient between them above 0.68. Similarly numbers of children in the household and household size were highly correlated with Pearson correlation coefficient above 0.7. Therefore the normality test for residuals using 'proc univariate' of SAS and Bruesch-Pagan test for constancy of variance test were conducted for models for years 2001 and 2009. The results indicated that both models satisfied the basic assumptions for regression models.

The models for years 2001 and 2009 explained 74.3% and 66.9% of variation in the household energy consumption for space cooling. Linear regression analyses of 2001 and 2009 show statistically significant variations in the household energy consumption for space cooling among various census divisions. For the year 2001 east north central division, west north central division and South Atlantic Division are not statistically significant in the model while for the year 2009 South Atlantic Division alone is not statistically significant in the model. This indicates the statistically significant variation occurs only in New England, East South Central, West South Central, Mountain and Pacific Census Divisions. The New England, Mountain and Pacific Census Divisions have consumed 17.1%, 36.5% and 42.4% less energy for household energy consumption for space cooling in 2001 with reference to energy consumption for space cooling in Middle Atlantic Census Division. A similar trend is seen in 2009 where the corresponding energy consumptions for space cooling for the above mentioned Census Divisions are less by 42%, 43.4% and 36.2%. In contrast, East South Central and West South Central

Census Divisions have consumed 18.4% and 18.0% more energy for space cooling in 2001 while in 2009 the Census divisions have consumed 25.7% and 14.0% more energy for space cooling with reference to energy consumption for space cooling in Middle Atlantic Division. The results indicate that, in spite of variations in household energy consumption for space cooling among Census Divisions, the trend in household energy consumption for space cooling among various Census Divisions is similar in 2001 and 2009. The variation in household energy consumption for space cooling among various census divisions is expected since Census Divisions spreads over different climatic zones (defined using a range of heating and cooling degree days) of the United States. For, example the summer usage of central air conditioning are 35%, 37%, 67% and 38% respectively for Northeast, Midwest, South, and West regions (RECS, 2009).

Among housing types, every housing type other than mobile homes is statistically significant in both the models for years 2001 and 2009. The single family attached units, homes in apartments with 2-4 units and homes in apartments more than 5 units have consumed respectively 11.1%, 9.6%, and 19.2% less energy for space cooling in 2001 whereas in 2009 the consumption for corresponding divisions are 12.8%, 9.4% and 15.4% less with reference to single detached family type homes. These variations in household energy consumption among various housing types for space cooling from this study are in line with the predictions by another earlier study that resulted in a similar variation and trend in household energy consumption for space cooling among various housing types (RECS, 2009).

Among the race/ethnic categories only the Hispanics category is statistically significant in the models for years 2001 and 2009 and this category has consumed 17.6% and 14.9% more energy for residential space cooling in 2001 and 2009 with reference to the race/ethnic category white.

The results from this study are similar to Lutzenhiser et al., 2008, in which the authors analyze household energy consumption. For example, in the aforementioned study investigated social structure and household electric energy consumption and found statistically significant variations in the use household electric energy among race/ethnic categories White and Hispanics. The same study with similar race/ethnic categories used in the present study showed no statistically significant variations in the household electric energy consumption among the remaining race/ethnic categories.

The result from Table 13 shows that there is no urban/rural differential in household energy consumption for space cooling. However, this result contradicts the other earlier findings that high levels of air conditioning space and usage in the suburban homes and higher density and small living spaces in the urban homes resulted in urban-rural differential in energy consumption for space cooling (Sanquist et al., 2012).

The results from table 13 indicate that there is considerable difference in energy consumption for space cooling among the households with centralized air conditioning and window/wall type air conditioning. The households with window/wall type air conditioning systems have consumed 48.2% and 40.9% less energy in 2001 and 2009 respectively for space heating with reference to households with centralized air conditioning equipment. The variations in the household energy consumption for central air conditioning and window/wall type air conditioning are dictated by a mix of housing types and age of the housing stocks. Besides, the ownership of the above two types of air conditioning equipment varies within and across the regions of the United States (RECS 2009). Thus the current result on differences in the household energy consumption for space cooling is justified and in line with the earlier finding (RECS 2009).

The results from table 13 shows that increase in the number of rooms in the households associated is with higher consumption of household energy for cooling. The result shows that addition of a room in the household resulting in 7.8% and 10.6% more household energy consumption in the households in 2001 and 2009 respectively. The positive association between household energy consumption and the total number of rooms and the floor area has been cited in numerous earlier research works (Auda et al., 2011; Theodoridou et al., 2011; Sanquist et al., 2012 and Steemers, 2009).

The results from table 13 also reveal that the householder's age is negatively associated with the household energy consumption for space cooling. However, the decrease in energy for household cooling for an increase in one year of householders' age is marginal and results in a decrease of 0.3% and 0.2% energy consumption in 2001 and 2009. The result of this study, the decrease in household energy consumption with the increase in householder's age, supports the findings in earlier literature on residential energy consumption for space cooling and occupant behavior (Steemers et al., 2009).

The results from table 13 also establish a positive linear relationship with the number of household members and household energy consumption for cooling. The figures from models indicate that increase in one household member resulting in an increase of 22.4% and 14.1% of energy required for cooling for the two years. This positive linear relationship between the number of household members and energy consumption for space cooling is supported by numerous earlier studies on household energy consumption (Steemers et al., 2009 and Yust et al., 2002).

Table 13 Regression coefficients with their exponential values for space cooling for years 2001 and 2009.

Variables	Year 2001 N=3464		Year 2009 N=9940	
	coefficients	Exp(Coef)	Coefficients	Exp(Coef)
Census Divisions				
New England Division	-0.188***	0.829	-0.046***	0.58
Middle Atlantic Division	ref		Ref	
East North Central Division	-0.075	0.928	-0.421***	0.656
West North Central Division	0.013	1.013	-0.297***	0.743
South Atlantic Division	0.04	1.041	0.06	1.062
East South Central Division	0.169**	1.184	0.229***	1.257
West South Central Division	0.165**	1.18	0.131**	1.14
Mountain Division	-0.455***	0.635	-0.569***	0.566
Pacific Division	-0.552***	0.576	-0.449***	0.638
Housing Type				
Mobile Home	-0.006	0.994	-0.001	0.999
Single-Family detached	ref		Ref	
Single-Family attached	-0.118***	0.889	-0.137***	0.872
Apartments with 2-4 units	-0.101***	0.904	-0.098***	0.906
Apartments with 5 or more units	-0.200***	0.818	-0.167***	0.846
Race/ethnicity				
White	ref		Ref	
Black	0.076*	1.076	0.017	0.984
Hispanics	-0.193***	0.824	-0.161***	0.851
Others	-0.161**	0.852	-0.06	0.942
Urban/rural				
Urban	ref		Ref	
Rural	0.02	1.02	0.033	1.034
Air conditioning equipment				
Central air conditioning	ref		Ref	
Window/wall type	-0.657***	0.518	-0.525***	0.591

Table 13 (Continued)

Other variables				
Total number of rooms	0.076***	1.078	0.101***	1.106
Householders' age	-0.003***	0.997	-0.002	1.002
Number of household members	0.202***	1.224	0.132***	1.141
Number of children	-0.112***	0.894	-0.056***	0.946
Number of Seniors	-0.657***	0.84	-0.047*	0.954
Cooling degree days	0.001***	1	0.001***	1.001
Household income	0.012*	1.012	0.025***	1.025
Electrical price	-19.107***	0	-14.033***	0

Note: ***$p \leq 0.001$ **$p \leq 0.01$ *$p \leq 0.05$

However, the results from table 13 show negative relationship with the number of children and senior citizens in the household. It indicates that addition of one more child with the number of children reduces the household energy consumption for cooling by 10.6% and 5.4% in 2001 and 2009 while addition of one more senior citizen with the number of senior citizens resulted in a reduction of 16.0% and 4.6% household energy consumption for cooling in 2001 and 2009. The preference for warm indoor condition by children and aged occupants is not very clear from earlier studies. For example, an earlier study on impact occupant behavior on residential energy consumption in Netherlands (Guerra Santin, 2011) could not arrive at a definite conclusion on warm indoor conditions required by children and aged occupants while another study on urban residential energy use have concluded a positive relationship between number of children and household energy consumption for cooling.

The number of cooling degree days in the model is associated with increased consumption of household energy for cooling, though increase in energy is very marginal. A unit increase in the number of cooling degree days in a year results in 0.1% of increase in energy consumption for space cooling in both the years 2001 and 2009. However, the number of cooling degree days is responsible for huge variations in household energy consumption since percentage of difference in cooling degree days among different climatic zones are higher. The importance of heating degree days and cooling degree days in the estimation household energy consumption variation is well documented in earlier literature (Steemers et al., 2009; Yust et al., 2002 and Ewing et al., 2008).

In both the models, the variable household income is associated with increase in household energy consumption for space cooling. The increase in income by a unit resulted in an increase in energy consumption for space cooling by 1.2% and 2.5% in 2001 and 2009 respectively. In contrast, electrical energy price is negatively associated with the household energy consumption for space cooling. The positive relationship between income and household energy consumption for cooling is supported by earlier work on residential energy consumption for space cooling (Steemers et al., 2009; Yust et al., 2002; Ewing et al., 2008 and Yun et al., 2011). Similarly, the negative association of price of the electricity with residential energy consumption is also well documented in literature and supported by many earlier works on residential energy consumption (Fell et al., 2012 and Hausfather et al., 2010).

Decomposition results and discussion

Table 14 and Table 15 lists the results from component analysis for individual variables and their exponential values to facilitate the following discussion based on these results.

Change in average household energy consumption for space cooling during 2001- 2009

The regression models for space cooling for years 2001 and 2009 predicts the mean household energy consumption as ($e^{8.5136}$) =4,982 thousand BTUs and ($e^{8.1183}$) =3355 thousand BTUs respectively. These results obtained in the present study show decrease of 32.7% in the average energy consumption for space cooling per household in 2009 when compared to the year 2001. These results support the findings by Department of Energy Administration in 2013 that there is a decrease in energy consumption of about 10% from 1993 to 2009 for space heating and cooling in the households in the United States (RECS 2009- Release date: March 7, 2013).

Change in household energy consumption for space cooling among Census Divisions during 2001- 2009:

Once we establish that there is a variation in the household energy consumption for space cooling for years 2001 and 2009 due to Census Divisions then a natural question that arises, "How far these variations in household energy consumption among Census Divisions in 2001 and 2009 contribute to the total change in the residential energy consumption for space cooling over the period 2001-2009?" The large contributor among Census Divisions to the change in household energy consumption over the period 2001-2009 is the East North Central Census Division and it contributed -5.3% to the total change in household energy consumption for space cooling. However this variable is not statistically significant in the model for the year 2001 hence a statistically meaningful result cannot be drawn for this Census Division. It is followed by West North Central Division with a contribution of -2.4% to the total change in cooling energy consumption and this division also is not statistically significant in RECS2001 model. Among the Census Divisions that are statistically significant in both the models, New England division and mountain division have contributed by -1.5% and -1.6% respectively to the total household cooling energy consumption over the period 2001-2009. East south Central Division and West South Central Division have contributed -0.3% and -0.6% respectively to the total change in the household cooling energy consumption and the Pacific Census division has contributed by 0.1% to the total residential cooling energy consumption over the period 2001-2009. The south

Atlantic Division is not statistically significant in both the models. It should be noted that the each contribution by Census Divisions is due to the regression coefficients and very little is attributed to the change in mean values of Census Divisions. It can also be noted that mean value correspond to the percentage of households surveyed in the Census Divisions and the change will be minimal in mean values since the same survey design employed by RECS administration for years 2001 and 2009.

Housing types and change in the household energy consumption for cooling during 2001-2009:

The various housing types in the models contributed very little to the observed trends in the household energy consumption during 2001-2009. The variable representing mobile homes is not statistically significant in both the models for years 2001 and 2009. In the statistically significant housing types such as single family attached type homes, homes in apartments with 3-4 units and homes in apartments more than 5 units contributed -0.4%, -0.1% and 0.2% to the total change in the household energy consumption for cooling, respectively. For single family attached homes the change in the mean value is contributes to the observed trend while for homes in apartments with more than 5 units, it is the change in coefficient that made the contribution to the total change in the energy consumption for cooling during 2001-2009.

Table 14 Decomposition analysis results for space cooling: 2001-2009

variables	Proportion of changes due to			
	Mean	Coefficients	Interaction	Sum
New England Division	0.000	-0.014	-0.001	-0.015
East North Central Division	0.000	-0.057	0.002	-0.055
West North Central Division	0.000	-0.026	0.001	-0.024
South Atlantic Division	0.000	0.005	0.000	0.004
East South Central Division	-0.001	0.005	0.000	0.003
West South Central Division	-0.002	-0.005	0.000	-0.006
Mountain Division	-0.009	-0.005	-0.002	-0.016
Pacific Division	-0.009	0.008	0.002	0.001
Mobile Home	0.000	0.000	0.000	0.000
Single-Family attached home	0.005	-0.002	0.001	0.004
Home in apartments with 2-4 units	0.001	0.000	0.000	0.001
Home in apartments with 5 or more units	-0.003	0.005	0.001	0.002
Black	0.001	-0.011	-0.002	-0.011
Other	-0.001	0.005	0.001	0.004
Hispanics	-0.014	0.001	0.002	-0.010
Rural home	0.001	0.002	0.001	0.004
Window/wall type air conditioning at home	0.019	0.038	-0.004	0.053
Total number of rooms	0.025	0.191	0.008	0.224
Householders' age	-0.002	0.248	0.002	0.248
Household size	0.009	-0.178	-0.003	-0.172
Square of household size	-0.005	0.005	0.000	0.000
Number of children in the household	0.002	0.026	-0.001	0.027
Number of seniors in the household	0.003	0.044	-0.002	0.045
Cooling degree days to base 65	-0.034	0.281	-0.013	0.234
Household income	0.004	0.081	0.005	0.089
Price of electricity per 1000 BTU	-0.176	0.140	0.047	0.011
Sum of proportion of changes	-0.185	0.787	0.045	0.647

Table 15 Exponential values of proportion of changes for space cooling

variables	Exponential values of			
	Mean	Coefficients	Interaction	Sum
New England Division	1.000	0.986	0.999	0.985
East North Central Division	1.000	0.944	1.002	0.947
West North Central Division	1.000	0.975	1.001	0.976
South Atlantic Division	1.000	1.005	1.000	1.004
East South Central Division	0.999	1.005	1.000	1.003
West South Central Division	0.998	0.995	1.000	0.994
Mountain Division	0.991	0.995	0.998	0.984
Pacific Division	0.991	1.008	1.002	1.001
Mobile Home	1.000	1.000	1.000	1.000
Single-Family attached home	1.005	0.998	1.001	1.004
Home in apartments with 2-4 units	1.001	1.000	1.000	1.001
Home in apartments with 5 or more units	0.997	1.005	1.001	1.002
Black	1.001	0.989	0.998	0.989
Other	0.999	1.005	1.001	1.004
Hispanics	0.986	1.001	1.002	0.990
Rural home	1.001	1.002	1.001	1.004
Window/wall type air conditioning at home	1.020	1.039	0.996	1.055
Total number of rooms	1.025	1.211	1.008	1.251
Householders' age	0.998	1.281	1.002	1.282
Household size	1.009	0.837	0.997	0.842
Square of household size	0.995	1.005	1.000	1.000
Number of children in the household	1.002	1.027	0.999	1.028
Number of seniors in the household	1.003	1.045	0.998	1.046
Cooling degree days to base 65	0.967	1.324	0.987	1.264
Household income	1.004	1.084	1.005	1.093
Price of electricity per 1000 BTU	0.839	1.150	1.048	1.011
Product of exponential values	0.831	2.197	1.046	1.910

Note: (1) Difference in intercepts in Log-linear models for years 2001 and 2009 -1.0423

(2) Exponential value difference in intercepts for years 2001 and 2009 0.3527

Race ethnic differences and change in the household energy consumption for cooling during 2001-2009:

Among the race/ethnic categories, only the Hispanics category is statistically significant in both the models for years 2001 and 2009. The contribution by the Hispanics category towards the total change in the household energy consumption during 2001-2009 is -1.0% and this contribution is due to change in the mean value in 2009 when compared to 2001. The race/ethnic categories Black and Other have contributed respectively by -1.1% and 0.4% to the total change in household cooling energy consumption and these contributions can be mostly attributed to the coefficients in the regression models. However, these two race/ethnic categories are not statistically significant in the model.

Rural/urban differences and the change in household energy consumption for cooling during 2001-2009:

The rural category does not contribute considerably to the total change in the household energy consumption for cooling during 2001-2009. Its contribution to total change in the energy consumption is 0.4% and a large fraction comes from the regression coefficients (0.2%), though the change in mean values of rural category has a reasonable share (0.1%) in that contribution to total change in the household energy consumption for cooling. However, it should be noted that in the regression models for years 2001 and 2009, the rural category does not show statistically significant variation in the household energy consumption for space cooling.

Wall/window type air conditioning use for cooling and the change in household energy consumption for cooling during 2001-2009:

The use of Window/wall type air conditioning for space cooling in homes is an important factor in the determination of variation in household energy consumption for space cooling. The decomposition results from table 15 show that this factor also has contributed significantly to the total change in energy consumption for cooling. The contribution by the type of air conditioning units i.e. window/wall mounts, to the total change in household energy consumption for cooling during 2001-2009 is 5.5% of which 2.0% is attributed to change in mean values (explained variation) in years 2001 and 2009 while 3.9% is attributed to regression coefficients (unexplained variation) in the models. The figures indicate that use of window/wall air conditioning plays significant role in the total change in energy consumption for cooling during 2001-2009.

Total number of rooms and age of the householders in the household and the change in household energy consumption for cooling during 2001-2009:

The role played by the total number of rooms in the household energy consumption for cooling is well documented in the literature. By extension, it should also play a crucial role in bringing in the change in household energy consumption at two different points of times. In the current study, this particular factor makes a huge contribution of 25.1% to the total change in energy consumption for residential cooling during 2001-2009. However, most of it, about 21.1% arrived from regression coefficients in the models whereas only 2.5% came from change in the mean values of total number of rooms. Therefore, most of the changes in total change in the household energy consumption for cooling due to the factor total number of rooms remain unexplained.

The other factor that makes up the bulk of the total change in household energy consumption for space cooling during 2001-2009 is the age of the householder. In this study this particular factor has contributed 28.2% to the total change in the household energy consumption for space cooling in 2001-2009. In this case all contribution from this factor to the total change in the household energy consumption came from regression coefficients. This indicates that almost all contribution by age of the householder to the total change in household energy consumption for cooling is unexplained.

The number of occupants in the household and its impact on the change in household energy consumption for cooling during 2001-2009:

In the regression models the occupants of the household are divided in to two sub groups: the number of children and number of senior citizens, to facilitate a better understanding of the change in the household energy consumption during 2001-2009. It can be seen from Table 15 that the total number of household members contributed -15.8% to the total change in the household energy consumption during 2001-2009 and most of it (16.3%) from the changes in the regression coefficients. The analysis also reveals that the contributions by factors, the number of children and number of senior citizens to the total change in the household energy consumption are respectively 2.8% and 4.6%. These contributions by the aforesaid three groups to the total change in the household energy consumption during 2001-2009 have come from the changes in the coefficients in the regression models, thus remain unexplained part of the total household energy consumption differences in space cooling for the years 2001 and 2009.

Cooling degree days and its impact on the change in household energy consumption for cooling during 2001-2009:

The importance of cooling degree days is well documented and it is considered that this is a unique, climate related factor that measures the household energy consumption for cooling (Sanquist et al., 2012). This fact is reemphasized in the current study and it contributes 26.4% to the total change in the household energy consumption for space cooling during 2001-2009 and most of it (32.4%) comes from the changes in regression coefficients in the models. The changes in the mean values and the factor that combines changes in means and regression coefficients have contributed 3.3% and 1.3% respectively to the total change in the household energy consumption for space cooling during 2001-2009. Thus, the number of cooling degree days has contributed more to the unexplained portion of total change in the household energy consumption during 2001-2009.

The effect of household income and electric energy price on the change in household energy consumption for cooling during 2001-2009:

The total household income is another crucial factor that determines the household energy consumption for space cooling. In the present study this factor contributes 9.3% to the total change in the household energy consumption during 2001-2009. Of this, 8.4% is due to the change in regression coefficients in the models for years 2001 and 2009, 0.4% is due to change in the mean values of income in 2001 and 2009 while the interaction of these changes has contributed by 0.5%. The decomposition analysis clearly shows that most of the contribution by the household income to the total change in the energy consumption for space cooling remains unexplained.

Energy price is another important agent that brings about changes in the household energy consumption. However, in the current model it contributes only 1.1% to the total change in the household energy consumption for cooling during 2001-2009. Though, the contribution is small it has components from the change in mean values, the change in regression coefficients and the change in both means values and regression coefficients and the components are respectively, 16.9%, 15.0% and 4.8%. In this case the change in mean values of the energy price (explained variation) offsets the change in regression coefficients and the change in both mean values and regression coefficients in the models (unexplained variation), thereby contributing very little to the total change in the household energy consumption for space cooling during 2001-2009.

The agents in trends in residential energy consumption for space cooling:

The final questions still remain. First, what are the major factors that affect the total change in household energy consumption for space cooling? Second, how all these factors together explain the total change in household energy consumption for space cooling during 2001-2009?

Our discussion on individual factors and their contribution to the total change in household energy consumption for space cooling reveals that the major contributors to the change are the use of window/wall type of air conditioning, total number of rooms in the household, age of the householder, number of household members, number of children in the household, number of senior citizens in the household, cooling degree days, total household income, and the price of electricity. Among various categorical variables New England and Mountain Census Divisions have contributed moderately to the change in the household energy consumption for space cooling during 2001-2009.

What is the cumulative change in scenario for household energy consumption for space cooling during 2001-2009?

Table 15 presents detailed results of decomposition analysis in household energy consumption for cooling between 2001 and 2009. As shown in Table 15, the changes in consumption due to the changes in intercepts, mean values, coefficients, and due to the change in both mean values and coefficients are computed separately for each independent variable. The estimates of each variable are then multiplied for each of the components to obtain the decomposition of differences in household energy consumption for space cooling.

Focusing on last row of the table 15, it can be seen that the measured difference in household energy consumption for space cooling is attributable to all components, namely the intercepts, mean values, regression coefficients, and to the interaction of both the mean values and regression coefficients. Of these, change in the intercepts account for 64.7% decrease in consumption, change in mean values account for 12.9% decrease in consumption, change in regression coefficients account for 119.7% increase in consumption and interaction of changes in both mean values and regression coefficients account for 4.6% increase in household energy consumption for space cooling. Altogether these components account for 32.7% decrease in household energy consumption for cooling between 2001 and 2009.

Continuing with the interpretation of these components, it is understandable that the change in intercepts is the measure of the change in the household energy consumption between 2001 and 2009 based on all proximate, socioeconomic and building structure variables included in the present study. The change in household energy consumption due to changes in mean values indicates that this part of the variation is completely explained in the model. Further, the changes in consumption due to changes in regression coefficients and interaction terms indicate that a part of the variation is not explained in the model. Therefore, the change in household energy consumption for space cooling is largely due to various unknown factors as revealed by regression coefficients in the models and this warrants further attention and investigation.

The theoretical framework for household energy consumption can now be revisited with special reference to the results obtained in the model. In this case the variation and change in the household energy consumption for space cooling by the Human Organisms specified by age of the householder, number of household members, number of children in the household, number of senior citizens in the household and the total household income is caused by Natural Environment specified by the cooling degree days and energy price in the model, and Social Environment represented by the thermostat setting preference (parsimonious model does not include this variable), and finally, Designed Environment specified by window/wall type air-conditioner and total number of rooms in the household. Thus, eco-system theory for household energy consumption provides a sound theoretical framework for the household energy consumption for the end use for space cooling.

Tests of hypotheses discussion:

The results from the regression model for the year 2009 on household energy consumption for space cooling can be used to test the research hypothesis that there are demographic, building structures, and behavioral factors associated with household energy consumption for space cooling in the United States. The statistically significant variables in the model for the year 2009 that determine the household energy consumption validates the research hypothesis that there are demographic, building structures, and behavioral factors associated with household energy consumption for space cooling, thereby rejecting the null hypothesis.

The current model for household energy consumption for space cooling shows statistically significant variation in energy consumption among most of the census divisions except for South Atlantic Division. Similarly among housing types, the influence in the variation in energy consumption is well pronounced except for mobile homes. Among the race/ethnic categories the variation in energy consumption occurs for the Hispanics category in the model for the year 2009. The other major variables that determines the variation in energy consumption for space cooling are window/wall type air conditioner, total number of rooms, household size, number of children, number of seniors, cooling degree days, household income and electric energy price.

The results from the regression based decomposition analysis for the period 2001-2009 on household energy consumption for space cooling also allows one to the test of the research hypotheses on the differences in household energy consumption among census divisions, race ethnic categories, and due to all variables in the models. The decomposition analysis indicates there is a variation in household energy consumption for space cooling, ranges from - 1.6% to 5.3% among census divisions during 2001-2009 rejecting the null hypothesis that there is no variation in the household energy consumption for space heating during 2001-2009. Similarly, the decomposition analysis shows a decrease of about 1.0% in household energy consumption for space cooling with race/ethnic categories Black and Hispanics. The variation in household energy consumption due to all variables in the model is 16.9% decrease due to the mean values and a 130% decrease due to unexplained variation.

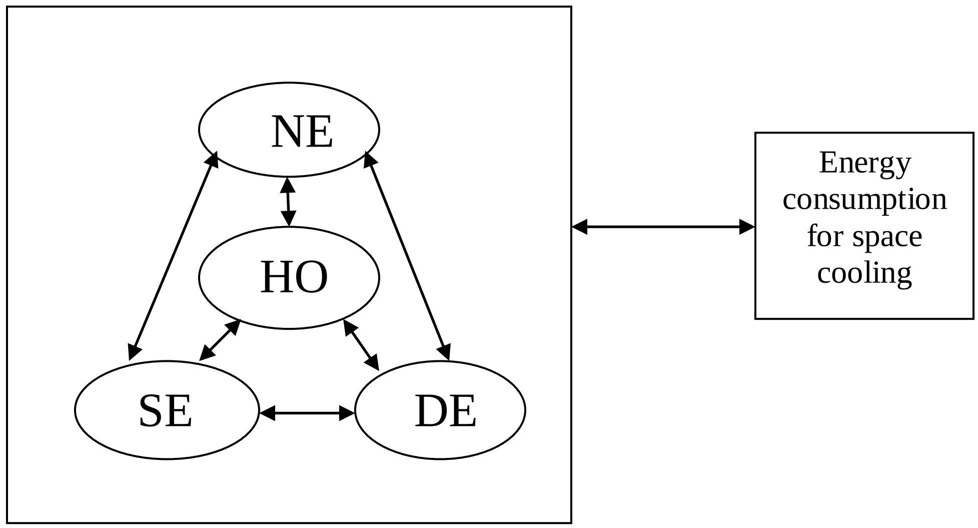

Figure 4 Eco-system model for household energy consumption for space cooling

Eco-system constituents for space cooling:

NE: Natural Environment – Geographical location, cooling degree days, Electric energy price, and Urbanity

SE: Social Environment – Cooling preferences.

DE: Designed Environment – Housing type, number of rooms in the household, type of air conditioner,

HO: Human Organism – Race/ethnicity, householders' age, number of children in the household, number of seniors in the household, and household income.

The unexplained variation in the model is the part that cannot be attributed to specific causes. This outcome from the decomposition analysis may be due to (1) change in the determinants of energy consumption since 2001, (2) due to variation in the performance of the cooling equipment (3) due to unknown non-linear behavior of variables in the models and (4) the unknown variation intrinsic to the system cannot be captured in the statistical models.

Limitations of this study for household energy consumption for appliance use:

One of the limitations of this study is that the models for years 2001 and 2009 is the use of the estimates of household energy consumption for space cooling as the outcome variable. This implies that any error in this variable might induce errors in the conclusions drawn from the model.

The RECS used different definitions for some variables during 2001 and 2009. For example, the variable urban/rural has only two categories in the survey for the year 2001 while it has four categories for the year 2009. Such different categorization in the survey for years 2001 and 2009 in variables might have distorted the results from these models.

In the survey for the year 2009 there are multiple entries for mixed races spread over various race/ethnic categories and might have induced some errors in the conclusions drawn here.

Finally, the determinants of household energy consumption for space cooling might have changed in the course of time since 2001 while the decomposition method uses the same group of determinants for the years 2001 and 2009. This might have caused some errors in the conclusions drawn from the model.

CHAPTER SEVEN: RESIDENTIAL ENERGY CONSUMPTION FOR WATER HEATING

Introduction

Residential energy consumption for water heating forms a major portion of total residential energy consumption, next only to space heating and appliances, in the United States. Estimates from the most recent Residential Energy Consumption Survey in the years 2010 and 2011, show that 17.7% of energy consumption in the U.S. homes in 2009 was for water heating, down from 18.3% in 1993. Further, the survey also reveals that residences use different fuels such as electricity, natural gas, propane/LPG, Fuel oil and other types of fuels for water heating in the United States. Besides, the survey also shows that the quantity and use of such fuels also vary by type of water heater, size of the water heater, age of the water heater, and type of housing unit. For the current study, the aforesaid factors provides a reasonable background, to understand both the trends in the residential energy consumption for water heating and the various policy changes in water and energy conservation efforts. Thus, the objective is to identify and quantify the factors that determine household energy consumption for residential water heating and consequently to make an effort to assess the effect of changes in these factors on the residential energy consumption for residential water heating in the United States between the years 2001 and 2009.

Dependent variable in the model

In the linear regression modeling of household energy consumption for water heating, the independent variable is the total amount of (estimated) energy used in the years 2001 and 2009 in thousand BTUs. For the years 2001 and 2009, the estimated energy consumption for water heating in RECS are provided individually for electricity, natural gas, fuel oil, propane/LPG, and for other types of fuels. Thus the total energy consumption for water heating for each household for the years 2001 and 2009 in thousand BTUs will be as follows:

Energy consumption for water heating

= Energy consumption due to (Use of electricity for water heating

+ Use of natural gas for water heating + Use of fuel oil for water heating

+ Use of Propane/LPG for water heating+ Use of kerosene for water heating)

In linear regression modeling the household energy consumption for water heating, the dependent variable is used as a non-zero continuous variable and the energy consumption is measured in BTUs.

Independent variables and their measurements

The regression models used here comprises of the variables corresponding to Census Divisions, race/ethnicity, urbanity, housing types, and fuels used for water heating and additional variables corresponding to the total number of rooms in the building, age of the householder, number of household members, heating degree days, household income, size of the water tank, presence of dishwasher, presence of heated pool. We also include variables that represent the preference in the use of washing machines. Further, the relationship between energy consumption and price has been well documented (Acton and Mitchell 1980, Reis et al 2008) and this relationship serves to identify consumer behavior towards price increase. For this reason the model also includes the average price of electricity paid by the consumer for water heating during the surveyed year.

The variables in the model that correspond to the Census Divisions, race/ethnicity, housing type, urbanity, presence of dishwasher, presence of heated pool, size of the water tank, and preference in the use of washing machine in the model are used as categorical variables. The preference in the use of washing machine are divided in to four categories namely, hot wash, warm wash, cold wash and no preference where no preference correspond to the category that have no washing machine. We choose the category that has no washing machine is as the reference category. The size of the water tank is made in to two categories, the first with capacity of 50 or more gallons (large size) and small size with a capacity of less than 50 gallons. The variables that correspond to the total number of rooms, the number of members, and income of the household in the previous 12-month period are treated as the cardinal variables in the model. The variables that relate the age of the householder, heating degree days and electricity price are treated as continuous variables. Since, the household size has a quadratic relationship to the energy consumed a squared term of household size is also included in the model.

Descriptive statistics

Table 16 shows the distribution of the 2001 and 2009 sample across all variables used in this regression analysis. The samples from both years reveal a similar trend in household energy consumption for water heating. In 2009 there is a very small increase of 1% as compared to the year 2001.

The samples also show no considerable change in the number of households surveyed among census divisions. In the Pacific census division about 1.5% less households is surveyed in 2009 as compared to 2001. Similarly among the housing types in 2009 about 4% more of single-family detached type homes, 4% less of single-family attached homes, and 1% less of homes in apartments with 2-4 units, and about 1% more of homes in apartments with 5 or more units, are surveyed as compared to the year 2001.

The samples further reveals that among various race/ethnic categories, in 2009 about 10% of white households, about 1% more of black households, and about 6.5% more of Hispanics households are surveyed as compared to the corresponding households surveyed in 2001. Likewise, among rural/urban categories about 5.5% more of rural households are surveyed in 2009 than the number of rural households surveyed in 2001. Among the water heating fuel types, while the use of electricity and propane/LPG in homes have increased by 3% and 1% respectively, the use of natural gas and fuel oil in homes decreased by 3% and 1% respectively. The use of other types of fuels also has decreased by a negligible percentage.

The ownership of water tanks with 50 or more gallons has increased by 7% and dishwasher ownership has increased by 3.5% in 2009 as compared to 2001. In the water usage preference in washing machine, there is a 6% decrease in the number of households preferring warm wash while a11% increase is noticed in the number used cold wash in 2009. It can also be seen that there is an increase in the washing machine ownership in the households by 4% in the year 2009. There is also a small increase in the number of households (0.7%) that have heated pools in 2009 as compared to the year 2001.

Table 16 Characteristics of categorical variables in the models for water heating for years 2001 and 2009

Variables	Year 2001 N=4688		Year 2009 N=12018	
	Number	Percentages	Number	Percentages
Census Divisions				
New England	242	5.04	584	4.86
Middle Atlantic	665	13.86	1617	13.45
East North Central	770	16.05	1877	15.62
West North Central	333	6.95	856	7.12
South Atlantic	912	19.01	2355	19.6
East South Central	306	6.39	754	6.28
West South Central	528	11.01	1351	11.25
Mountain	301	6.28	837	6.97
Pacific	739	15.41	1787	14.87
Housing Type				
Mobile Home	306	6.39	729	6.06
Single-Family detached	2827	58.95	7617	63.38
Single-Family attached	475	9.9	713	5.94
Apartments with 2-4 units	427	8.9	953	7.93
Apartments with more units	760	15.85	2006	16.69
Race/ethnicity				
White	3715	77.49	8103	67.42
Black	583	12.16	1619	13.47
Hispanics	258	5.37	1547	12.87
Others	239	4.98	750	6.24
Urban/rural				
Urban	3995	83.33	9317	76.55
Rural	800	16.68	2701	22.47
Heating fuels				
Electricity	1836	38.29	4980	41.44
Natural Gas	2613	54.5	6207	51.65
Propane/LP Gas	132	2.75	445	3.7
Fuel Oil	206	4.3	381	3.17
Other fuels	8	0.16	6	0.05

Table 16 (continued)

Water tank size 50 gallons				
Yes	1214	25.31	3983	33.14
No	3581	74.69	8035	66.86
Heated Pool				
Yes	53	1.1	218	1.82
No	4742	98.9	11800	98.18
Use of Dishwasher at home				
Yes	2252	53.04	7164	59.61
No	2543	46.96	4854	40.39
Washing Preferences				
Hot wash	279	5.82	617	5.14
Warm wash	2228	46.47	4758	39.59
Cold wash	1264	26.37	4517	37.59
No washing machine	1023	21.34	2125	17.69

Note: Race/ethnicity percentage totals exceed 100% due to the reason that 1.1% of respondents have chosen more than one race/ethnic category.

Table 17 Characteristics of ordinal and continuous variables for water heating in the models for years 2001 and 2009

Variables	Mean 2001	Mean 2009
Energy consumption for water	15799	15975
Total number of rooms	7.48	5.93
Householders’ age	49.66	50.24
Number of household members	2.56	2.58
Heating degree days to base 65	3985.5	4198.2
Household income	6.11	6.58
Price of electricity	0.03	0.04

Note: 1) Mean Household income between 6 and 7 indicates that the mean income is between $40,000 and $50,000.

The mean values in Table 17 for the remaining variables do not show a significant change in year 2009 as compared to the year 2001 except for the variables that correspond to the total number of rooms in the household and heating degree days. In the case of the number of rooms there is a decrease in the number of rooms by 2.5% while there are 283 heating degree days (an increase) in the year 2009 as compared to the year 2001.

Regression model results and discussion

Table 18 shows the results of regression modeling of household energy consumption for water heating in 2001 and 2009. The table also details the coefficients and their exponentials of coefficients of the models for 2001 and 2009. The models for the years 2001 and 2009 explain 64.3% and 52.2% of variation in the household energy consumption for space cooling.
Linear regression analyses of 2001 and 2009 show statistically significant variations in the energy consumption among the census divisions. For the year 2001 every other Census Division other than Mountain division is not statistically significant in the model while for 2009 east north central, west north central, South Atlantic, Mountain and Pacific Census Divisions are statistically significant in the model. This indicates that the statistically significant variation occurs only in Mountain Census Divisions for the years 2001 and 2009. The Mountain Census Division consumed 8.2% less energy in 2001 for water heating with reference to Middle Atlantic Census Division. In 2009 East North Central, West North Central, South Atlantic, Mountain and Pacific Census Divisions have consumed 10.1%, 14.7%, 10.1%, 18.2% and 14.3% less energy as compared to Middle Atlantic Census Division. The results indicate widely varying trends in energy used to heat water in years 2001 and 2009. In 2001 there is no variation in the energy consumed in various Census Divisions while the variation among Census Divisions is very apparent in the year 2009.

Table 18 Regression coefficients with their exponential values for water heating for years 2001 and 2009

Variables	Year 2001 N=4688		Year 2009 N=12018	
	Coefficients	Exp(Coef)	Coefficients	Exp(Coef)
Census Divisions				
New England Division	0.159	1.036	-0.023	0.978
Middle Atlantic Division	ref		ref	
East North Central Division	0.004	1.004	-0.107**	0.899
West North Central Division	-0.019	0.981	-0.159***	0.853
South Atlantic Division	-0.042	0.959	-0.106**	0.899
East South Central Division	-0.003	0.997	-0.066	0.936
West South Central Division	0.017	1.017	-0.057	0.944
Mountain Division	-0.085*	0.918	-0.201***	0.818
Pacific Division	-0.05	0.952	-0.154***	0.857
Housing Type				
Mobile Home	0.086**	1.09	0.104***	1.109
Single-Family detached	ref		ref	
Single-Family attached	0.021	1.021	-0.096***	0.909
Apartments with 2-4 units	-0.074*	0.928	-0.011	0.989
Apartments with 5 or more units	-0.078*	0.925	-0.162***	0.85
Race/ethnicity				
White	ref		ref	
Black	0.184***	1.202	0.141***	1.152
Hispanics	-0.026	0.974	-0.03	0.988
Others	-0.053	0.949	-0.012**	0.97
Urban/rural				
Urban	ref		ref	
Rural	0.062**	1.064	-0.028**	0.973
Heating fuels				
Electricity	ref		ref	
Natural Gas	0.817***	2.263	0.742***	2.099
Propane/LP Gas	0.504***	1.655	0.460***	1.585
Fuel Oil	1.325***	3.763	0.579***	1.784
Other fuels	0.730***	2.076	0.753*	2.123
Size of the water tank 50 or more gallons				
Yes	0.102***	1.108	0.167***	1.181
No	ref		ref	

Table 18 (Continued)

Heated pool at home				
Yes	-0.129	0.879	0.181	1.198
No	ref		ref	
Use of Dishwasher at home				
Yes	0.079***	1.083	0.065**	1.068
No	ref		ref	
Preferences in the use of washing machine				
Hot wash	0.417***	1.517	0.414***	1.512
Warm wash	0.367***	1.443	0.361***	1.435
Cold wash	0.347***	1.415	0.335***	1.398
No washing machine	ref		ref	
Other variables				
Total number of rooms	0.019***	1.019	0.249***	1.033
Householders' age	-0.002***	0.998	0.001	1.001
Number of household members	0.271***	1.311	0.249***	1.283
Heating degree days to base 65	0.000***	1	0.000**	1
Household income	0.008*	1.008	0.002	0.998
Electrical price in dollars/1000 BTU	-7.873***	0	-7.531***	0.001

Note: ***$p \leq 0.001$ **$p \leq 0.01$ *$p \leq 0.05$

Among housing types, all housing types other than single attached homes is statistically significant for year 2001 while all types other than apartments with 2-4 units is statistically significant for year 2009. As a result only mobile homes and apartments with 5 or more units are statistically significant in both the models. Mobile homes used 9.0% and 10.9% more energy for water heating in 2001 and 2009 with reference to the single detached homes. The apartments with 5 or more units have consumed 7.5% and 15.0% less energy for water heating in 2001 and 2009 respectively with reference to single-detached homes. In 2001 apartments with 2-4 units consumed 7.2% less energy for water heating while in 2009 single-family attached units consumed 9.1% less energy for water heating with reference to single detached homes. This suggests that there is a variation in the energy consumption for water heating among various dwelling types, which was also pointed in earlier work (Aydinalp et al., 2004).

Among the race/ethnic categories, only the Black category is statistically significant consuming 20.2% and 15.2% more energy for residential water heating in 2001 and 2009 with reference to the race/ethnic category White. In 2009 model the race/ethnic category 'Other' is statistically significant and consumed 3.0% less energy for water heating as compared to the race/ethnic category White. The literature on race/ethnic differences in residential energy consumption for water heating is meager and work that focused on residential energy consumption for water heating were localized studies with small samples with no scope to predict race/ethnic differences (Evarts et al., 2013 and Lutz et al., 1996). However, in some previous work, the authors predict race/ethnic differences in the residential energy consumption (Lutzenhiser et al., 2008) that supports the findings from our models.

The regression model results from Table 18 reveal clear rural/urban divide in the residential energy consumption for water heating. The rural category is statistically significant in both the models for years 2001 and 2009. However, the models show opposing trends in the years 2001 and 2009. In 2001 the rural homes have consumed 6.4% more energy as compared urban homes while in 2009 the rural homes have consumed 2.7% less as compared to urban homes. The opposing trends may be partly due to the different rural/urban definitions employed by RECS in 2001 and 2009 surveys. The rural/urban differences shown in the models is supported by a recent study on impact of life style on household energy consumption that predicted more frequent use of washing machines and dishwashers resulting in higher household energy consumption in the rural households (Sanquist et al., 2012).

Table 18 also provides information about the variation in household energy consumption for residential water heating among different types of fuels used. The models show that all types of fuels are statistically significant in years 2001 and 2009. In terms of BTU's the natural gas consumption for space heating in 2001 and 2009 are respectively 2.3 and 2.1 times respectively the electric energy consumption for water heating. Similarly, in terms of BTU's propane/liquefied petroleum gas consumption for space heating in 2001 and 2009 are respectively 1.7 and 1.6 times the electric energy consumption for residential water heating. The trend for Fuel oil for water heating is slightly different from natural gas and LP gas. In terms of BTU's, Fuel Oil consumption in 2001 and 2009 are respectively 3.8 and 1.8 times the electric energy used for water heating. There appears to be a decrease of 50% consumption of Fuel Oil for water heating in 2009 as compared to the consumption of fuel oil for water heating in 2001. In case of other types fuels in 2001 and 2009 the energy consumption for water heating are 2.1 times in both years as compared to the electric energy consumption for water heating. The results are supported by Energy Information Administrations' (EIA) assertion that household's choice of heating fuel is dependent on factors such as the decision on primary heating equipment is made by the householder or building contractor and availability of types of fuels in that area. As a result the choice of the fuel varies significantly from region to region in the United States (RECS, 2009).

Another important factor that determines the variation in the household energy consumption for water heating is the size of the water tank. The sizes of the water tanks in the households have been made in to two categories large and small where the size of the water tank 50 or more gallons correspond to large size and the rest correspond to small size. Table-16 shows that the regression coefficients of the size of the water tank in both the models are statistically significant. Further, it also shows that those households that own water tank of size 50 or more gallons have consumed 10.8% and 18.1% more energy for water heating in 2001 and 2009 with reference to those households that owned a smaller water tank of size less than 50 gallons. The variation in household energy consumption for water heating and its association with size of the water tanks and their energy requirement factors have been pointed out in earlier studies (Aguilar et al., 2005 and Aydinalp et al., 2004) and their results correspond to the results from the current study.

The next factor in the study of variation of energy consumption for water heating in the households is the presence of heated pool in the household. The results from the models show that variation in energy consumption for water heating in the households in 2001 and 2009 indicating opposite trends. In 2001, the households with heated pool have consumed 12.1% less energy and in 2009, the energy consumption for the households with heated fuels is up by 19.8% with reference to those households with no heating pool. However, in the regression model for year 2001 the variable heated pool is not statistically significant thereby making it difficult to draw any statistically significant conclusions regarding the trends in household energy consumption for water heating. The increased use of household energy consumption for water heating in the households with heated pools is well documented in many earlier studies (Meier et al, 1992, Parker, 2002). For example, one earlier study predicted that household energy consumption for households with heated pools increased by 4,200 KWh/year (Parker, 2002) another study predicted an increased energy consumption of 500-4000 KWh/year for the households with heated pools (Meier et al., 1992).

Dish washer in the household is an appliance that uses hot washer on day to day basis and a major factor that influence the variation in the household energy consumption for water heating. Its importance as a contributor to household energy consumption has been discussed in the household energy consumption for appliance use too. In the current study the results from regression model results shows that the variable dish washer is statistically significant in both models for years 2001 and 2009. In the year 2001 and 2009 the households with dish washer have consumed 8.3% and 6.8% more energy for household energy consumption than the households with no dishwashers. The results from regression models suggest decreasing trend in the household energy consumption for dishwasher thereby reducing energy consumption for water heating in the households with dishwashers. The variation in household energy consumption has been a topic of interest and many earlier studies have emphasized its importance in the household energy consumption (Meier et al., 1992; Sanquist et al., 2012 and Hoak et al., 2008). One earlier study has predicted that households with dishwashers consumed 0.4 KWh to 1.3 Kwh per cycle, depending on the efficiency and usage pattern of the dishwasher (Hoak et al., 2008).

Many earlier energy consumption models have attached greater importance to the presence of washing machines and usage patterns of washing machines and its influence in assessing the variance in the household energy consumption. In the current model the variable that corresponds to washing machine has been made in to four categories that reflect the presence of washing machine and usage pattern in the household. The results from table 16 show that all these categories that correspond to use of washing machines in the households are significant in both the models for years 2001 and 2009. The households that preferred hot wash have consumed 51.7% and 51.2% more energy for water heating in 2001 and 2009 with reference to the energy consumed in the households with no washing machines. Similarly, the households that preferred warm wash have used 44.3% and 43.5% less energy for years 2001 and 2009 while the households that preferred cold wash have consumed 41.5% and 39.8% more energy for years in 2001 and 2009 with reference to the households with no washing machine. In all the categories the results for years 2001 and 2009 indicate decreasing trend in the household energy consumption for the households with washing machines. This trend may be due to the use of modern technology resulting in increased efficiency of the new washing machines. A study of washing machines has concluded that old washing machines wash less efficiently and consume more resources as compared to the newer machines (Stamminger, 2005).

Like every other end use, in case of household energy consumption for water heating too, there is a strong association between the total number of rooms in the household and the energy consumption for water heating. The results from table show that total number of rooms in the household is statistically significant in the models for household energy consumption for water heating in years 2001 and 2009. In the year 2001 the addition of a room with the number of rooms in the household resulted in an increase in the household energy consumption by 1.9% while in 2009 it resulted in 3.3% increase in household energy consumption for water heating. The results indicate an increasing trend in the household energy consumption for water heating per room over the period 2001-2009. The results from this study reemphasizes the strong association of total number of rooms or total built in area to the household energy consumption for every end use that has been well documented in the literature (Aydinalp et al., 2004; Ewing et al., 2008; Hausfather et al., 2010 and Steemers et al., 2009).

As pointed out in the earlier paragraph, besides total number of rooms, the household size is also strongly associated with household energy consumption for each end use. In the current study, the regression models for year 2001 and 2009 show that household size is statistically significant in both models. In 2001 and 2009, an increase in number of household members by one person resulted in 31.1% and 28.3% increase in the household consumption of energy for water heating. The results show a decreasing trend in the energy consumption for water heating per person in the household. An earlier study on domestic hot water consumption predicted that though, there is a decrease in per capita total water use in the households with the increase in household size, there is an increased use of hot water consumption in the households with the increase in the household size (Evarts et al., 2013). This particular result is in support of the result from the current study that there is a decreasing trend in the energy consumption for water heating in the households.

The results from table 18 show that the variables householders' age and the total household income are not statistically significant in the model for energy consumption for water heating in the year 2009 while they are statistically significant in the model for the year 2001. This means that it is not possible to draw statistically meaningful results on trends in the household energy consumption for water heating. Besides, though the variables are statistically significant in the regression model for the year 2001 their contribution to variation in the household energy consumption for water heating is very little. In this model while householders' age accounted for 0.2% decrease in energy consumption for water heating per year increase in the householders' age, the household income have accounted for 0.8% increase in the energy consumption for water heating per unit increase in income. These two variables that are not significant in the regression model for year 2009 do not provide a clear understanding of their association with household energy consumption for water heating. The literature show that some of the earlier studies have excluded householders' age from modeling energy consumption for water heating (Sanquist et al., 2012 and Aydinalp et al., 2004). The earlier studies that have included total household income in the model have found that, not only this variable is significant in the model but also possess a linear relationship between income and energy consumption for water heating (Aydnalp et al., 2004). The result from the current study that household income is not statistically significant in the model for household energy consumption for water heating negates earlier finding from other studies (Aydnalp et al., 2004 and Guerin et al., 2000).

The variables heating degree days and price of electricity, though statistically significant in the models for years 2001 and 2009, have not contributed much to the variation in the household energy consumption for years 2001 and 2009. Consequently, there two variables in the current models are of little use in tracking the trends in the energy consumption for water heating. However, their statistical significance in the model shows their association with the energy consumption for water heating. After all, this part of the result is consistent with the earlier studies on energy consumption for water heating (Hausfather et al., 2010; Reis et al., 2008 and Aydnalp et al., 2004).

Decomposition results and discussion

Table 19 and Table 20 show results of decomposition analysis for individual variables in the model and their exponential values. The following discussion is based table 19 and table 20.

Change in average household energy consumption for water heating during 2001- 2009

The regression models for water heating for years 2001 and 2009 predicts the mean household energy consumption as ($e^{9.42915}$) =12,446 thousand BTUs and ($e^{9.41817}$) =12310 thousand BTUs respectively. These results obtained in the present study show decrease of 1.09% in the average energy consumption for water heating per household in 2009 when compared to the average energy consumption per household for the year 2001. These results support the findings by Department of Energy Administration in 2013 that there is decreased energy consumption of about 3.3% from 1993 to 2009 for water heating in the households in the United States (RECS 2009- Release date: March 7, 2013).

Change in household energy consumption for space cooling among Census Divisions during 2001- 2009:

The decomposition results from table 20 show that Census divisions have contributed considerably, values ranging from 0.3% to 1.5%, to the total change in the household energy consumption for water heating. However, as pointed out earlier, that all Census Divisions, except the Mountain Census Division, are not statistically significant in the regression models for years 2001 and 2009. Therefore, discussion on Contribution of Census Divisions will be limited to Mountain Census Division. This Census Division has contributed by -0.9% to the total change in the household energy consumption for water heating during 2001-2009. From the results it can be seen that most of the contribution is from change in regression coefficients (-0.7%) which means that most of its contribution to the total change in the household energy consumption is unexplained.

Housing types and change in the household energy consumption for water heating during 2001-2009:

The various housing types in the models have contributed very little to the trends in the household energy consumption during 2001-2009. The single attached homes and homes in apartments with 2-4 housing units are not statistically significant in one of the models for years 2001 and 2009. Of the statistically significant housing types in both models mobile homes and homes in apartments with 5 or more units have contributed respectively by 0.1% and -1.5% to the total change in the household energy consumption for water heating. In this case most of the contribution by homes in apartments with 5 or more units have come from change in coefficients in the models, thus contribute to unexplained portion of total change in household energy consumption for water heating during 2001-2009.

The contribution by single attached home types and homes in apartments with 2-4 units to the total change in energy consumption for water heating for the period in discussion is -0.8% and 0.6% respectively. However, these two variables are not statistically significant in one of the models for years 2001 and 2009.

Race ethnic differences and change in the household energy consumption for water heating during 2001-2009:

The decomposition result from table 20 shows among the race/ethnic categories the Black category alone is statistically significant in both the models for years 2001 and 2009. The contribution by Black category for the total change in the household energy consumption during 2001-2009 is -0.3% and this contribution is due to changes in mean values and coefficients in the models. The race/ethnic categories Hispanics and Other have contributed respectively by -0.2% and 0.2% to the total change in household energy consumption for water heating. However, these race/ethnic groups are not statistically significant either on both or in one of the models, besides contributing very little to total change in the household energy consumption for water heating over the period 2001-2009.

Table 19 Decomposition analysis results for water heating

variables	Proportion of changes due to			
	Mean	Coefficients	Interaction	sum
New England Division	0.000	-0.003	0.000	-0.003
East North Central Division	0.000	-0.018	0.000	-0.017
West North Central Division	0.000	-0.010	0.000	-0.010
South Atlantic Division	0.000	-0.012	0.000	-0.013
East South Central Division	0.000	-0.004	0.000	-0.004
West South Central division	0.000	-0.008	0.000	-0.008
Mountain Division	-0.001	-0.007	-0.001	-0.009
Pacific Division	0.000	-0.016	0.001	-0.015
Mobile Home	0.000	0.001	0.000	0.001
Single-Family attached home	-0.001	-0.012	0.005	-0.008
Home in apartments with 2-4 units	0.001	0.006	-0.001	0.006
Home in apartments with more units	-0.001	-0.013	-0.001	-0.015
Black	0.002	-0.005	-0.001	-0.003
Other	-0.001	0.002	0.001	0.002
Hispanics	-0.002	0.000	0.000	-0.002
Rural home	0.004	-0.015	-0.005	-0.017
Water heating fuel is natural gas	-0.023	-0.041	0.002	-0.062
Water heating fuel is Propane/LPG	0.005	-0.001	0.000	0.003
Water heating fuel is fuel oil	-0.015	-0.032	0.008	-0.039
Other water heating fuels	-0.001	0.000	0.000	-0.001
Total number of rooms	-0.029	0.102	-0.021	0.052
Household Size	0.004	-0.055	0.000	-0.052
Square of household size	-0.004	0.004	0.000	0.000
Householders' age	-0.001	0.136	0.002	0.136
Heating degree days to base 65	0.003	0.099	0.005	0.107
Total household income	0.004	-0.060	-0.005	-0.061
Size of the water tank at home	0.008	0.016	0.005	0.029
Dishwasher at home	0.005	-0.007	-0.001	-0.003
Washing preference is hot wash	-0.003	0.000	0.000	-0.003
Washing preference is warm wash	-0.025	-0.002	0.000	-0.027
Washing preference is cold wash	0.039	-0.003	-0.001	0.034
Heated fuel at home	-0.001	0.003	0.002	0.005
Price of electricity per 1000 BTU	-0.069	0.010	0.003	-0.057
Sum of proportion of changes	-0.103	-0.054	-0.003	-0.053

Table 20 Exponential values of proportion of changes for water heating

variables	Exponential values proportion of changes due to			
	Mean	coefficient	Interaction	Sum
New England Division	1.000	0.997	1.000	0.997
East North Central Division	1.000	0.982	1.000	0.983
West North Central Division	1.000	0.990	1.000	0.990
South Atlantic Division	1.000	0.988	1.000	0.987
East South Central Division	1.000	0.996	1.000	0.996
West South Central division	1.000	0.992	1.000	0.992
Mountain Division	0.999	0.993	0.999	0.991
Pacific Division	1.000	0.984	1.001	0.985
Mobile Home	1.000	1.001	1.000	1.001
Single-Family attached home	0.999	0.989	1.005	0.992
Home in apartments with 2-4 units	1.001	1.006	0.999	1.006
Home in apartments with more units	0.999	0.987	0.999	0.985
Black	1.002	0.995	0.999	0.997
Other	0.999	1.002	1.001	1.002
Hispanics	0.998	1.000	1.000	0.998
Rural home	1.004	0.985	0.995	0.984
Water heating fuel is natural gas	0.977	0.960	1.002	0.940
Water heating fuel is Propane/LPG	1.005	0.999	1.000	1.003
Water heating fuel is fuel oil	0.985	0.968	1.008	0.962
Other water heating fuels	0.999	1.000	1.000	0.999
Total number of rooms	0.971	1.108	0.979	1.053
Household Size	1.004	0.946	1.000	0.949
Square of household size	0.996	1.004	1.000	1.000
Householders' age	0.999	1.146	1.002	1.146
Heating degree days to base 65	1.003	1.104	1.005	1.113
Total household income	1.004	0.942	0.995	0.941
Size of the water tank at home	1.008	1.016	1.005	1.030
Dishwasher at home	1.005	0.993	0.999	0.997
Washing preference is hot wash	0.997	1.000	1.000	0.997
Washing preference is warm wash	0.975	0.998	1.000	0.973
Washing preference is cold wash	1.040	0.997	0.999	1.035
Heated fuel at home	0.999	1.003	1.002	1.005
Price of electricity per 1000 BTU	0.933	1.010	1.003	0.945
Product of exponential values	0.902	1.055	0.997	0.948

Table 20 (continued)

Note (1) Difference in intercepts of Log-linear models for years 2001 and 2009	0.0419
(2) Exponential value of difference in intercepts for years 2001 and 2009	1.0428

Rural/urban differences and the change in household energy consumption for water heating during 2001-2009:

The decomposition analysis results from table 20 show that the rural homes do contribute considerably to the total change in the household energy consumption for water heating during 2001-2009. The contribution of rural homes to the total change in household energy consumption for water heating is 1.6% to which all components of decomposition, that is mean values, regression coefficients and interaction of mean values and regression coefficients have contributed equally well to the change in total household energy consumption for water heating. It appears that in rural homes there is slight decrease in the energy consumption for water heating during 2001-2009.

Shift and change in fuel consumption and total change in the household energy consumption for water heating:

The decomposition results from table 20 shows the various types of fuels used for water heating and their contribution to the total change in household energy consumption for water heating during 2001-2009. The results from table 18 shows that all fuel types used in the households are statistically significant in both the models for years 2001 and 2009. Further, the results show that the contribution of natural gas to the total change in the household energy consumption is higher as compared to the other types of fuels whereas other fuels have contributed least to the total change in the household energy consumption for water heating during 2001-2009. During this period Natural gas, Propane/LPG, Fuel oil and other fuels have contributed by -6.0%, 0.3%, -

3.8%, and -0.1% respectively to the total change in the household energy consumption for water heating. The contribution to the total change in energy consumption for water heating due to change in means for natural gas, Propane/LPG, Fuel oil and other types of fuels are respectively, -2.3%, 0.5%, -1.5%, and -0.1% while their contribution to total change in energy consumption for water heating by regression coefficients are -4.0%, -0.1%, -3.2% and 0% respectively. The figures show partial contributions by change means and regression coefficients of types of fuels to the total change in household energy consumption for water heating. The results imply that the use of natural gas, fuel oil and other types of fuels for water heating have decreased over the period 2001-2009 while the use of fuel oil for water heating have increased marginally over the same period.

Size of the water tank and total change in the household energy consumption for water heating during 2001-2009:

The table 20 shows that the size of the water tank, a larger size tank with capacity 50 gallons or more contributes 3.0% to the total household energy consumption for water heating over the period 2001-2009. Of this contribution, 0.8% and 1.6% have come from change in means and change in coefficients respectively indicating that its contribution to unexplained variation of the total change in the household energy consumption is higher. The result is an indication of increased consumption of energy by larger capacity water tanks by households for water heating during the period 2001-2009.

Total number of rooms and the total change in the household energy consumption for water heating during 2001-2009:

The total number of rooms in the household is a major factor that brings in change in the household energy consumption. The table 20 shows that the total number of rooms account for

5.3% in the total change in the household energy consumption for water heating during 2001-2009, of that -2.9% and 10.8% are from mean values and regression coefficients in the model. The interaction of means and regression coefficients contributes another -2.1% to the total household energy consumption for water heating. This variable shows opposing trends in means and regression coefficients in its contribution to the total change in the household energy consumption during the period 2001-2009.

Number of household members and householders' age and the total change in the household energy consumption for water heating during 2001-2009:

The number of household members is a crucial factor in bringing about the change in the household energy consumption. As shown in the table 18, it contributes by -5.1% to the total change in household energy consumption during 2001-2009 of which 0.4% and -5.4% are from means and regression coefficients respectively. Indeed, a major portion of its contribution is to unexplained variation in the change in the household energy consumption for water heating. Similarly, the contribution of householders' age to the total change in the household energy consumption for water heating is 14.6% and most of it from regression coefficients of the models. However, householders' age is not statistically significant in one of the models for years 2001 and 2009.

Heating degree days and the total change in the household energy consumption for water heating during 2001-2009:

The variable heating degree days is a unique variable that measures the impact of climatic condition upon the residence independent of indoor comforts and conditions. Obviously, it is yet another major factor that decides the change in the household energy consumption for water heating. As the table 18 shows, this factor contributes very considerably to the total change in the household energy consumption for water heating by 11.3%. However, a major portion of it, 10.4% arrived from regression coefficients while a small portion of it 0.3% arrived from change in mean values. In this case the interaction of mean and coefficients also has contributed by 0.5% to the total change in household energy consumption for water heating. This result cannot be construed as a supporting factor for climatic change since the heating degree days reflect the climatic conditions of the years 2001 and 2009.

The impact of dishwasher over the change in the household energy consumption for water heating:

Dishwasher and use patterns of dishwasher are other agents that bring in the variation in the change in the household energy consumption over a period of time. However, in the current study it contributes marginally to the total change in the household energy consumption for water heating. Its contribution to total change in the household energy consumption is -0.3% and both mean values and coefficients have contributed by 0.5% and -0.7% towards this total change in the household energy consumption for water heating.

Preferences in the use of washing machine and the change in the household energy consumption for water heating:

The results from the decomposition table show the contributions by hot wash, warm wash and cold wash in the use of washing machines to the total change in the household energy consumption during 2001-2009. In the current study, contrary to expectations, the cold wash has contributed more by 3.5% to the total change in the household energy consumption for water heating of that 4.0% is from mean values while 0.3% is from coefficients. In this case variation in the change in the household energy consumption for water heating is almost explained. In case of warm wash and hot wash preferences the contributions are -2.7% and -0.3% respectively to the total change in the household energy consumption for water heating during 2001-2009. Of these, -2.5% and -0.3% are from changes in mean values while -0.2% and 0% are from change in coefficients. This mixed trend in the washing preferences may be due to the usage patterns such as frequency of use and other factors that have not been included in the current study.

What is the change in scenario for household energy consumption for water heating during 2001-2009?

Table 20 presents detailed results of decomposition analysis in household energy consumption for water heating between 2001 and 2009. As shown in table 20 changes in consumption due to changes in intercepts, mean values, coefficients, and due to change in both mean values and coefficients computed separately for each independent variable. Then estimates of each variable were multiplied for each of the component to obtain the decomposition of differences in household energy consumption for water heating.

Now, an inspection of the last row of the table 20 shows that the measured difference in household energy consumption for space cooling is attributable to all components, namely intercepts, mean values, regression coefficients, and to interaction of both mean values and regression coefficients. Of these, change in intercepts account for 4.2% increase in consumption, change in mean values account for 8.8% decrease in consumption, change in regression coefficients account for 5.5% 1ncrease in consumption and interaction of changes in both mean values and regression coefficients account for 0.3% increase in household energy consumption for space water heating. Altogether these components account for 1.1% decrease in household energy consumption for water heating between 2001 and 2009.

Again continuing with the interpretation of these components it is understandable that the change in intercepts is the measure of change in the household energy consumption between 2001 and 2009 based on all proximate, socio economic and appliance usage variables included in the present study. The change in household energy consumption due to changes in mean values indicates that this part of the variation in household energy consumption is completely explained in the model. Further, the changes in consumption due to changes in regression coefficients and interaction terms indicate the part the variation in the household energy consumption for water heating not explained in the model. Therefore, the emerging trend in the change in household energy consumption for water heating is largely due to play of various unknown factors responsible for variation in household energy consumption in water heating as revealed by regression coefficients in the models.

Now, theoretical framework for household energy consumption can be compared with special reference to the results obtained in the model for household energy consumption for water heating. In this case the variation and change in the household energy consumption for water heating by the Human Organisms specified by age of the householder, number of household members, household income, and race/ethnicity of the householder, is caused by Natural Environment specified by the cooling degree days, energy price and rural/urban differences in the model, and Social Environment specified by washing preferences of the household, and finally, Designed Environment specified by size of the water tank, presence dishwasher, and total number of rooms in the household. Thus, eco-system theory for household energy consumption provided a basic theoretical ground work for the household energy consumption for the end use for water heating.

Tests of hypotheses discussion:

The results from the regression model for the year 2009 on household energy consumption for water heating is the test for the research hypothesis that there are demographic, building structure, and behavioral factors associated with household energy consumption for space heating in the United States. In fact, the following statistically significant variables in the model for the year 2009 determine the household energy consumption for water heating thereby rejects the null hypothesis and accepts the research or alternative hypothesis.

The current model for household energy consumption for water heating shows statistically significant variation in energy consumption for water heating among most of the census divisions except for New England Division, East South Central Division and West South Central Division. Similarly among housing types in the variation in household energy consumption for water heating is substantial except for apartment hones with 2-4 units. Among the race/ethnic categories the variation in household energy consumption for space heating occurs for the Black and Others categories in the model for the year 2009. The other major variables that determines the variation in household energy consumption for water heating are urban/rural, water heating fuels, size of the water tank, heated pool, use of dishwasher, washing machine use preferences, total number of rooms, age of the householder, household size, heating degree days, household income and electric energy price.

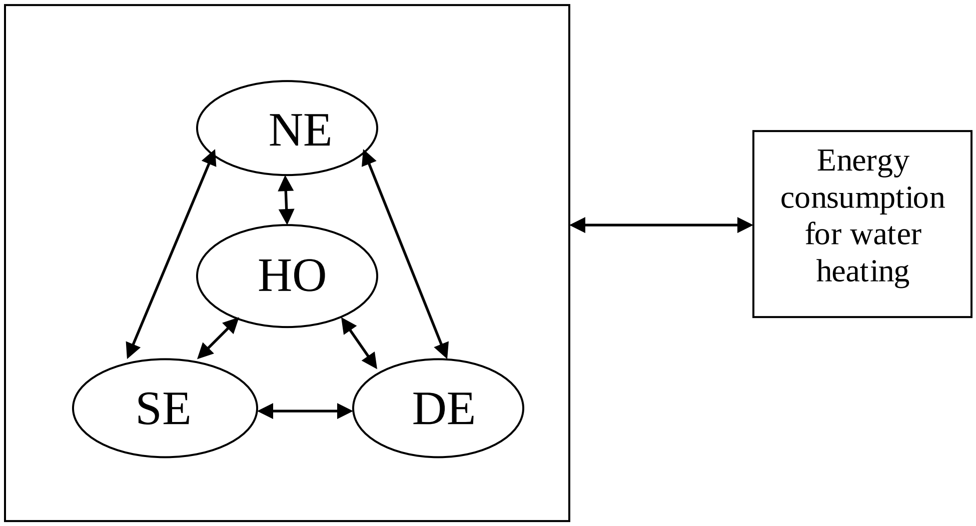

Figure 5 Eco-system model for household energy consumption for water heating

Eco-system constituents for water heating:

NE: Natural Environment – Geographical location, heating degree days, Electric energy price, and Urbanity

SE: Social Environment – Washing preferences

DE: Designed Environment – Housing type, number of rooms in the household, water heating fuel, dishwasher, cloth washing machine and size of the water tank.

HO: Human Organism – Race/ethnicity, householders' age, and household income.

The results from the regression based decomposition analysis for the period 2001-2009 on household energy consumption for space heating provides the test of research hypotheses for differences in household energy consumption for water among census divisions, among race ethnic categories, among use of stove fuels, and due to all variables in the models. The decomposition analysis indicates there is variation in household energy consumption for water heating, decreasing from 1.0% to 1.7% among census divisions during 2001-2009 rejecting the null hypothesis that there is no variation in the household energy consumption for space heating during 2001-2009. Similarly, the decomposition analysis shows a variation of less than 1.0% in household energy consumption for water heating among race/ethnic categories. Among water heating fuels there is a decrease in the use of natural gas by 6.0% and a decrease in the use of fuel oil by 3.8%. The variation in household energy consumption for water heating due to all variables in the model is 9.8% decrease due to mean values and 5.2% decrease due to unexplained variation in the model.

The unexplained variation in the model is the one that cannot be attributed to specific causes. The unexplained variation in the decomposition analysis may be due to (1) change in the determinants of household energy consumption for water heating over time since 2001, (2) type of water heating equipment such as tank water heaters or tank less water heaters (3) due to different brands of water heating equipment showing variation in performance (5) due to unknown non-linear behavior of variables in the models and (6) the unknown variation intrinsic to the system cannot be captured in the statistical models.

Limitations of this study for household energy consumption for water heating:

One of the serious limitations of this study is that the models for years 2001 and 2009 use the estimated values of household energy consumption for space heating as the outcome variable. This means that any error in this outcome variable may have induced errors in the conclusions drawn from the model.

The RECS have used different definitions for some variables during 2001 and 2009. For example, the variable urban/rural has only two categories in the survey for the year 2001 while it has four categories for the year 2009. Such different categorization in the survey for years 2001 and 2009 in variables might have distorted the results from these models.

In the survey for the year 2009 there are multiple entries for mixed races spreading over to various race/ethnic categories. This might have induced some errors in the conclusions drawn from the model.

Finally, the determinants of household energy consumption for water heating might have changed in the course of time since 2001 and the decomposition method has used same group of determinants for the years 2001 and 2009. This might have caused some errors in the conclusions drawn from the model.

CHAPTER EIGHT: OVERALL SUMMARY OF FINDINGS

This chapter provides the summary of the findings from the models for household energy consumption for end uses appliance use, space heating, space cooling and water heating with reference to research questions outlined in Chapter-1.

What are the current demographic factors, building structure factors, and behavioral factors are associated with the different end uses of the household energy consumption in the United States?

The current model for household energy consumption for appliance use shows very clear statistically significant variation in energy consumption for appliance use among various census divisions and housing types in United States. Among the race/ethnic categories the variation in household energy consumption for appliance use occurs only for the Black category in the model for the year 2009. The other major variables that determines the variation in household energy consumption for appliance use are urban/rural, stove fuels, separate freezer, dish washer, dryer, outdoor lights, aquarium, computer, fax, number of color televisions, number of rooms in the household, household size, age of the refrigerator, light bulb use patterns and electricity price.

The current model for household energy consumption for space heating shows statistically significant variation in energy consumption for space heating among most of the census divisions except for New England Division and East South Central Division. Similarly among housing types in the variation in household energy consumption for space heating is substantial except for mobile homes. Among the race/ethnic categories the variation in household energy consumption for space heating occurs for the Black and Hispanics categories in the model for the year 2009. The other major variables that determines the variation in household energy consumption for space heating are space heating fuels, building vintage categories, home insulation categories, floor categories, total number of rooms, age of the main heating equipment, age of the householder, thermostat use patterns, heating degree days, household income and electric energy price.

The current model for household energy consumption for space cooling shows statistically significant variation in energy consumption for space cooling among most of the census divisions except for South Atlantic Division. Similarly among housing types in the variation in household energy consumption for space cooling is well pronounced except for mobile homes. Among the race/ethnic categories the variation in household energy consumption for space cooling occurs for the Hispanics category in the model for the year 2009. The other major variables that determines the variation in household energy consumption for space cooling are window/wall type air conditioner, total number of rooms, household size, number of children, number of seniors, cooling degree days, household income and electric energy price.

The current model for household energy consumption for water heating shows statistically significant variation in energy consumption for water heating among most of the census divisions except for New England Division, East South Central Division and West South Central Division. Similarly among housing types in the variation in household energy consumption for water heating is substantial except for apartment hones with 2-4 units. Among the race/ethnic categories the variation in household energy consumption for space heating occurs for the Black and Others categories in the model for the year 2009. The other major variables that determines the variation in household energy consumption for water heating are urban/rural, water heating fuels, size of the water tank, heated pool, use of dishwasher, washing machine use preferences, total number of rooms, age of the householder, household size, heating degree days, household income and electric energy price.

Are there are significant differences in the household energy consumption for different end uses in different geographic areas such as Census Bureau designated divisions in the United States since 2001?

A review of table 5, the regression based decomposition table shows very little variation of less than 1% in the household consumption for appliance use among the various Census Divisions indicating that there is no considerable variation in the energy consumption for appliance use in the United States from 2001 to 2009.

A review of the table 10 indicates the same trend in the household energy consumption for space heating during 2001-2009. The variations in household energy consumption for space heating among various Census Divisions are less than 1% except for South Atlantic Division which has an increased energy consumption of 1.4% and West South Central Division which has a decreased energy consumption of 1.5%. The results indicate that there very little variation in the household energy consumption for space heating among the various Census Divisions in the United States from 2001-2009.

A review of the table 15 indicates a different trend in the household energy consumption for space cooling during 2001-2009. There is an increase in the household energy consumption for space cooling among New England, East North Central, and West North Central Census Divisions by 1.5%, 5.3% and 2.4% respectively while in the Mountain Division there is a decrease in energy consumption for space cooling by 1.6% from the year 2001 to 2009. In all other Census Divisions the variations in the consumption of energy for space cooling are less than 1% during the period 2001-2009. The results indicate that the variation in household energy consumption for space cooling in some of the Census Divisions considerable while on others it is negligible in the United States during the period 2001-2009.

A review of the table 20 indicates a similar trend, like space cooling, in the household energy consumption for water heating during 2001-2009. There is a decrease in the household energy consumption for water heating among East North Central, West North Central, South Atlantic and Pacific Census Divisions by 1.7%, 1.0%, 1.3% and 1.5% respectively, during the period 2001-2009. In all other Census Divisions the variation in the consumption of energy for water heating is less than 1% during the period 2001-2009. The results indicate that the variation in household energy consumption for space cooling in some of the Census Divisions considerable while on others it is negligible in the United States during the period 2001-2009.

Are there significant changes in race/ethnic differences in the household energy consumption for different end uses over time since 2001?

Referring to Table 5, the regression based decomposition table indicates that there is no variation in the consumption of energy for household appliances among different race/ethnic categories in the United States during the period 2001-2009. The table shows a negligible increase in the household energy consumption for appliance use, 0.1%, 0.1% and 0.4% increase for various race/ ethnic categories Black, Hispanics, and Others with reference to race/ethnic category White in the model.

From Table 10, the regression based decomposition shows very little variation in the consumption of energy for space heating among different race/ethnic categories during the period 2001-2009. The table shows a small decrease of 1.2% for Black category, a small decrease of 0.3% for Hispanics category, 0.3% for Others category, as compared to White category in the model during the period 2001-2009. The results indicate there is very little variation in the household energy consumption for space heating among various race/ethnic groups in the United States.

In table 15 it is seen that the regression based decomposition shows very little variation in the consumption of energy for space cooling among different race/ethnic categories during the period 2001-2009. The table shows a small decrease of 1.1% for Black category, a small decrease of 1.0% for Hispanics category, 0.4% for Others category, as compared to White category in the model during the period 2001-2009. The results indicate there is very little variation in the household energy consumption for space cooling among various race/ethnic groups in the United States.

Referring to Table 20, the regression based decomposition shows very little variation in the consumption of energy for space heating among different race/ethnic categories during the period 2001-2009. The table shows a small decrease of 0.3% for Black category, a small decrease of 0.2% for Hispanics category, 0.2% for Others category, as compared to White category in the model during the period 2001-2009. The results indicate there is very little variation in the household energy consumption for water heating among various race/ethnic groups in the United States.

Is there a shift in household energy consumption from other sources of energy consumption in the households (such as natural gas, liquefied petroleum gas etc.) to electrical energy in different end uses over time since 2001?

Referring to Table 5, the regression based decomposition analysis of household energy consumption for appliances indicates that with reference to changes in the energy consumption of electricity for stoves, there is very little change in the use of natural gas, liquefied petroleum gas, and other types of fuels in the year 2009 as compared to the year 2001. There is a decrease in the use of natural gas by 0.2%, increase in the use of liquefied petroleum gas by 0.4% and a decrease in the use of other fuels by 0.4% for stoves in the year 2009 as compared to the year 2001, suggesting that there is no major shift from one type of stove fuel to another type of stove fuel during the period 2001-2009.

Reviewing Table 10, the regression based decomposition analysis of household energy consumption for space heating indicates that with reference to changes in the use of electricity for space heating, there are considerable changes in the use of natural gas, liquefied petroleum gas, fuel oil, and other types of fuels in the year 2009 when compared to the year 2001. There is an increase in the use of natural gas by 10.1%, increase in the use of liquefied petroleum gas by 2.3%, an increase in the use of fuel oil by 1.6%, and decrease in the use of other fuels by 0.6% for space heating in the year 2009 as compared to the year 2001, suggesting a shift from electricity to other fuels for space heating. However, since the increased use of a particular fuel depends upon various factors such as availability of particular type of fuel in that area, efficient heating equipment availability, and principal-agent problems, one cannot conclude that there is a major shift from one type of space heating fuel to another type of space heating fuel in the United States during the period 2001-2009.

Electricity is used as the main source of power for space cooling in most of the U.S. homes and EIA does not include any other source of fuel for space cooling in the RECS. Therefore, the question of shift in the use of fuel for space cooling does not arise and a discussion on this is excluded.

Reviewing Table 20, the regression based decomposition analysis of household energy consumption for water heating indicates that with reference to the changes in the household energy consumption of electricity for water heating, there is considerable change in the use of natural gas, liquefied petroleum gas, fuel oil, and other types of fuels in the year 2009 as compared to the year 2001. There is a decrease in the use of natural gas by 6.0%, increase in the use of liquefied petroleum gas by 0.3%, a decrease in the use of fuel oil by 3.8%, and a negligible decrease in the use of other fuels for water heating in the year 2009 as compared to the year 2001, suggesting an increased use of electricity for water heating. However, since the increase or decrease in the use of a particular fuel depends upon various factors such as availability of particular type of fuel in that area, type of the water tank, and the type of fuel used for space heating, we cannot conclude that there is a major shift from one type of water heating fuel to another type of water heating fuel in the United States during the period 2001-2009.

How far do the changes in the factors associated with the household energy consumption change in the household energy consumption for different end uses over time since 2001?

A question that has to be answered in this dissertation is the cumulative effect of factors on the household energy consumption for each end use during the period 2001-2009. This can be addressed by the cumulative results obtained in regression based decomposition table for each of the end uses.

The last row of table 5 shows the cumulative changes in the household energy consumption during the period 2001-2009 due to the changes in various factors that determine the energy consumption for appliances. The figures indicate there is an increase of 4.1% in the household energy consumption for appliances from 2001 to 2009. It can also be seen from the table that changes in the average values of the determinants result in a decreased energy consumption of 11.7%, while the unknown factors intrinsic to the system resulted in an increased energy consumption of 18.0% for the appliance use from 2001 to 2009. This suggests that an increased efficiency of household appliances might have played a role in the small increase in the household energy consumption for appliance use.

The last row in the table 10 provides us with the cumulative changes in the household energy consumption during the period 2001-2009 due to changes in various factors that determine the energy consumption for space heating. The figures show a decrease of 44.2% in the household energy consumption from 2001 to 2009. It can also be seen from the table, that changes in the average values of the determinants resulted in a decreased energy consumption of 16.9%, while the unknown factors intrinsic to the system decreased the energy consumption by 33.0%. This suggests that an increased efficiency of heating equipment and energy conservation practices might have played a role in the huge decrease in household energy consumption for space heating in the United States.

The last row in the table 15 provides us with the cumulative changes in the household energy consumption during the period 2001-2009 due to changes in the various factors that determined the household energy consumption for space cooling. The figures show an increase of 91.0% in the energy consumption. It can also be seen from the table, that changes in the average values of the determinants resulted in a decreased energy consumption of 16.9%, while the unknown factors intrinsic to the system resulted in a two fold increase (130%) in energy consumption for space cooling from 2001 to 2009. This suggests that an increased efficiency of cooling equipment and changing climatic conditions have played a role in the big increase in the energy consumption for space cooling in the United States.

The last row in the table 20 provides us with the cumulative changes in the household energy consumption during the period 2001-2009 due to changes in various factors that determine the household energy consumption for water heating. The figures indicate there is a decrease of 5.2% in the energy consumption for water heating from 2001 to 2009. It can also be seen from the table, that the changes in the average values of the determinants resulted in a decreased energy consumption of 9.8%, while the unknown factors intrinsic to the system resulted in an increased energy consumption of 5.2%. This suggests that an increased efficiency of water heating systems and climatic changes might have played role in the decrease in the household energy consumption for water heating in the United States.

Contribution of constituents of eco-system to variation in residential energy consumption for appliance use:

Table 21 shows variation in household energy consumption for different end uses in terms of human organism, natural environment, social environment and the designed environment. The contribution by human organism to variation in household energy consumption for appliance use is 6.8% of which -0.4% and 7.2% corresponds to explained and unexplained variations, respectively. The huge contribution of unexplained variation by human organism to the total variation in the energy consumption may be due to the non-inclusion of other variables such as household income, age groups of the occupants, and may be due to very limitation of the survey design.

The contribution of natural environment to variation in household energy consumption for appliance use is -8.2% of which 6.6% and -2.1% corresponds to explained and unexplained variations, respectively. The huge contribution of unexplained variation by natural environment to total variation in the household energy consumption may be due to the random nature of energy prices on appliances and may be due to the limitation of the survey design.

Table 21 Results due to constituents of eco-system model for variation in residential energy consumption for different end uses: 2001-2009

Constituents of eco-system model	Variation that is		
	Explained	Unexplained	Total
Appliance use:			
Human Organism	0.996	1.072	1.068
Natural Environment	0.918	1.066	0.979
Social Environment	1.001	0.987	0.988
Designed Environment	0.965	1.045	1.008
Space heating:			
Human Organism	1.005	0.908	0.912
Natural Environment	1.029	0.816	0.839
Social Environment	1.012	1.130	1.144
Designed Environment	0.794	0.803	0.638
Space cooling:			
Human Organism	1.003	1.243	1.247
Natural Environment	0.795	1.448	1.151
Social Environment	1.000	1.000	1.000
Designed Environment	1.042	1.279	1.332
Water heating:			
Human Organism	1.006	1.014	1.020
Natural Environment	0.938	1.019	0.956
Social Environment	1.011	0.993	1.004
Designed Environment	0.945	1.025	0.969

The contribution by social environment to variation in household energy consumption for appliance use is -1.2% of which 0.1% and -1.3% corresponds to explained and unexplained variations, respectively. There is a major contribution of unexplained variation by social environment to the total variation in the household energy consumption for appliance use. However, the total variation being -1.2% is very small and does not warrant any further investigation.

The contribution of the designed environment to variation in household energy consumption for appliance use is 0.8% of which -3.5% and 4.5% correspond to explained and unexplained variations, respectively. The contribution of the explained and unexplained variation by designed environment to total variation in energy consumption for appliance use being not very different and this implies that the unexplained variation may be due to the variations intrinsic to the system.

Contribution of constituents of eco-system to variation in residential energy consumption for space heating:

Table 21 shows variation in household energy consumption for different end uses in terms of human organism, natural environment, social environment and designed environment. The contribution by human organism to the variation in the household energy consumption for space heating is -8.2% of which 0.5% and -9.2% corresponds to explained variation and unexplained variation respectively. The huge contribution of unexplained variation by human organism to total variation in the household energy consumption for space heating may be due to very limitation of the survey design.

The contribution of the natural environment to variation in household energy consumption for space heating is -16.1% of which 2.9% and -18.4% corresponds to explained variation and unexplained variation respectively. The huge contribution of the unexplained variation by the natural environment to the total variation in the household energy consumption may be due to impact of unpredictable energy price changes and climatic changes on space heating.

The contribution by social environment to variation in household energy consumption for appliance use is 14.4% of which 1.2% and 13.0% corresponds to explained variation and unexplained variation respectively. There is a huge contribution of unexplained variation by the social environment to total variation in the household energy consumption. This variation may be due to the unaccounted lifestyle factors of the occupants and are not included in the model.

The contribution of designed environment to variation in household energy consumption for space heating is -36.2% of which -20.6% and -19.7% correspond to explained and unexplained variations, respectively. There is a huge contribution of unexplained variation by the designed environment to total variation to the energy consumption for space heating and this implies that the unexplained variation may be due to the unaccounted factors in insulation, use of fuels and efficiency of heating equipment.

Contribution of constituents of eco-system to variation in residential energy consumption for space cooling:

Table 21 shows the variation in household energy consumption for different end uses in terms of human organism, natural environment, social environment and designed environment. The contribution by human organisms to the variation in household energy consumption for space cooling is 24.7% of which 0.3% and 24.3% corresponds to explained and unexplained variation respectively. The huge contribution of unexplained variation by human organism to total variation in the household energy consumption for space cooling may be due to very limitation of survey design.

The contribution of the natural environment to the variation in household energy consumption for space cooling is 15.1% of which -20.5% and 44.8% corresponds to explained variation and unexplained variation respectively. The huge contribution of unexplained variation by natural environment to total variation in the household energy consumption for space cooling may be due to impact of unpredictable electric energy price changes and climatic changes on use of energy for space cooling.

There is no contribution by the social environment to the variation in household energy consumption for space cooling since no variables correspond to social environment are modeled due to the parsimonious approach to the model.

The contribution of the designed environment to variation in household energy consumption for space cooling is 33.2% of which 4.2% and 27.9% correspond to explained and unexplained variations, respectively. There is a huge contribution of unexplained variation by designed environment to total variation of energy consumption for space cooling implying that the unexplained variation may be due to the unaccounted factors in insulation and efficiency of cooling equipment.

Contribution of constituents of eco-system to variation in residential energy consumption for water heating:

Table 21 shows the variation in household energy consumption for different end uses in terms of human organism, natural environment, social environment and designed environment. The contribution by human organism to the variation in the household energy consumption for water heating is 2.0% of which 0.6% and 1.4% corresponds to the explained and unexplained variations, respectively. The contribution of unexplained variation by human organism to total variation is small does not warrant any further investigation.

The contribution of the natural environment to the variation in the household energy consumption for water heating is -4.4% of which -6.2% and 1.9% corresponds to explained and unexplained variations, respectively. The contribution of unexplained variation by natural environment to total variation in the household energy consumption for water heating is small, and does not warrant any further investigation.

The contribution by social environment to variation in household energy consumption for appliance use is 0.4% of which 1.1% and 0.07% corresponds to explained variation and unexplained variation respectively. The contribution of unexplained variation by the social environment to total variation in the household energy consumption for water heating is small, and does not warrant any further investigation.

The contribution of the designed environment to the variation in the household energy consumption for appliance use is -3.1% of which -5.5% and 2.5% corresponds to explained and unexplained variations, respectively. Here too, the contribution of unexplained variation by designed environment to the total variation in the household energy consumption for water heating is small and does not warrant any further investigation.

Theoretical framework and the overall results for research questions:

The earlier discussion on research questions and the results show that there is a range of variables corresponding to the Human Organisms that determine the variation in household energy consumption for different end uses. The range of variables includes race/ethnic categories, household size, household income, number of children in the household, number of elderly in the household, and age of the householder.

There is also a range of variables that correspond to Natural Environment which determine the variation in household energy consumption for different end uses. This includes Census Divisions, urban/rural categories, electric energy price, number of heating degree days, and number of cooling degree days over which the consumer has no control.

In the case of variables related to the Social Environment, some of which determine the variation in household energy consumption for different end uses are listed in the following. In this case, the range of variables includes preferences in thermostat setting, cloth wash preferences, dishwasher use patterns, and preferences for outdoor lights, which correspond to behavioral patterns and cultural background of the occupants.

Another important range of variables that correspond to Designed Environment and which determine the variation in household energy consumption for different end uses are listed now. In this case, this includes all household appliances, heating equipment, cooling equipment, insulation and floor types, building vintage categories, size of the water tank, and the number of rooms in the household over which the occupants have control to redesign, alter, and modify depending on their needs.

In the terms of the eco-system theory, all these four environments, both individually and interacting with each other, bring about the changes in the household energy consumption for each end use. In fact, the earlier discussions on each of the end uses were about the variation brought in by these Human Organism, Natural Environment, Social Environment, and Designed Environment in the household energy consumption for different end uses. Thus, the eco-system theory on household energy consumption provided an excellent background for the analytical study of household energy consumption for different end uses.

CHAPTER NINE: RELEVANCE OF THIS STUDY TO POLICY ISSUES

Relevance of this study on energy consumption for appliance use on policy issues:

The residential energy consumption accounts for 31% of the total energy production in the U.S. and addressing appliance energy consumption is necessary because of its present consumption and likely the future growth. The current efforts to address these issues are twofold: First the efficiency improvements of appliances and second, the conservation measures in the use of appliances (Kelly et al., 2012). However, the thrust has to be on improving the efficiency since conservation measures very little scope in the reduction of household energy consumption.

The current study shows the household equipment like dishwasher, dryer, color televisions, computers, and refrigerators play a crucial role in the increase of energy consumption. Besides, the list also includes smaller miscellaneous appliances such as cell phones, hair dryers, coffee makers, juicers etc., though they were not included in the current study. Therefore any policy measure should target these household appliances for considerable reduction in the energy consumption for appliance use.

Technological improvements are instrumental in improving energy efficiency of household appliances, especially for small household appliances. In the U.S. large efforts and consequently considerable development have already occurred in this front. For example, the energy star dishwashers use 30% less energy than a standard model and heat pump dryers offers a possibility of saving 50% more energy over the conventional dryers. Similarly combined IR-microwave heating technology offers 75% reduction in conventional baking time (Bansal et al., 2011). Though, innovation helped improve efficiency of household appliances, the initial cost and payback period poses major hurdles for promoting these modern energy efficient appliances. Therefore, the federal and state governments need to develop a policy measures to subsidize and encourage the purchase of such energy efficient appliances.

In the U.S., the minimum energy efficiency standards for household appliances brought in considerable reduction household energy consumption. For example, the past decades have witnessed a huge drop in prices and energy consumption for refrigerators with a simultaneous increase in their capacities. The new energy efficiency standards aim for further reduction in refrigerator and freezer energy use by up to 30% by 2014, in cloth washers to by 26% energy by 2018, in dryers to increase the efficiency by 5% in 2015, and in dishwashers to save 14% energy by 2013 (Bansal et al., 2011). However, these standards also demand new policy instruments to remove from sale the less efficient devices and to increase the efficiency of the whole range of appliances. Policy intervention in these areas by federal and state governments will greatly accelerate the implementation of these standards in the industry and in the market.

The major focus so far, is on implementing minimum efficiency standards for major household appliances such as dryer, refrigerators etc., while the growing segment of household electronic items have not received adequate attention in implementing the any efficiency standards. In the United States, nearly a third of the households own four devices ranging from cell phones to laptop computers plugged in and charging most of the time at home (RECS, 2009), besides standby power for set top boxes and audio equipments consume considerable electricity at home. Though, enacting standards for these small household appliances is difficult, the federal government needs to come up with new types of policy and regulatory measures to conserve and curb considerable portion of household energy consumption.

Relevance of this study to policy issues on space heating and space cooling:

The study predicts that most of the energy consumed for space heating in the United States is from natural gas and fuel oil. There is a decreased use of natural gas consumption by 50% in the households for space heating since 1990. This decrease in consumption in households is partly due to the increased efficiency of the heating furnaces used in the holds. For example, the furnaces in 1980s were 65% energy efficient while the furnaces in 2000s are 80% energy efficient (CERA, 2009). This suggests that an energy efficient furnace is instrumental in reducing household energy consumption of natural gas for space heating at homes. In this regard, the federal agencies need to come up with new minimum energy performance standards for new heating furnaces for households. Besides, incentives and tax subsidies to encourage the households to replace the energy inefficient furnaces with energy efficient new natural gas and fuel oil furnaces will be very useful.

The study also predicts that the vintage homes categories and wall insulation as major factors in household energy consumption for space heating. In this aspect the current trend in the United States is very encouraging. There is a shift in building energy efficient ENERGY STAR homes from the conventional homes. In 2008, nearly 110,000 ENERGY STAR qualified homes were built in the United States (EIA, 2010). The energy efficiency of these homes is assessed based on a set criterion, which includes effective insulation, high performance windows and efficient heating and cooling equipment. This demands that the new policies should aim at enacting stricter building codes at both local and federal level with a focus on the reduction household energy consumption. Federal agencies may also enter in to voluntary agreements with the local and national builders to implement policies on energy efficient homes.

The modern air conditioners consume 30%-50% less energy to produce the same amount of cooling as the counterparts made in 1970s. The modern air conditioners that are currently marketed also feature a programmable thermostat with which the consumer may set times for its operation in the household. There are ENERGY STAR air conditioners with labeling that contain SEER ratings and room air conditioners with labeling that contain EER ratings. However such air conditioners carry a high price tag and require higher initial cost (DOE, 1999). In the energy consumption for space cooling this barrier in purchasing energy efficient equipment dictates the policy issues. Certain utility providers encourage buying ENERGY STAR equipment by reimbursing some or all of the price difference. However, intervention of federal agencies by subsidizing the purchase by enacting various policies and initiating incentives at local and regional level will further reduce the energy consumption for cooling.

The product purchase decision in air conditioning also plays a crucial role in the reduction of household energy. For example, households in hot climates require a room air conditioner with EER rating 10 while the homes in warm climates need a room air conditioner with EER rating 9 which consume different amounts of energy for cooling. Further, the decision on the size of the air conditioner depends on volume of space cooled, number of windows, and tree shades over the roof. Therefore, an appropriate policy intervention is at local level by providing assistance and information about various products in the market for the consumers to make right purchase and installation decisions.

The study also identifies the occupant behavior in thermostat setting as a major factor in the household energy consumption for space heating and cooling. Earlier research on occupant behavior shows that energy use of different occupants living in identical residential units can vary as much as 200% to 300% (Lutzenhiser, 1987). Therefore, in the energy conservation context, the occupants need to be educated about energy saving behaviors. Programmable thermostats and smart meter installations at homes is an effort in this direction to bring in the energy conservation awareness among the occupants. On the other hand, smart metering also help utility companies to manage the transmission load to the households. Some smart metering services may also inform the households the times the increase in transmission loads goes up resulting in higher electricity price (Harney et al, 2009). These observations indicate that the utility companies should come up with policies not only to educate their consumers about potential energy savings behaviors but also to improve their services to their customers.

The study also has identified minority race/ethnic category Black and senior householders as major factors in household energy consumption for space heating while race/ethnic category Hispanics and number of children are major factors in household energy consumption for space cooling. This necessitates that minority groups Black, Hispanics, elderly people and children may be made as the target group in enacting energy conservation policies. Supporting this group through various policies is in line with reduction in the household energy consumption for space heating and cooling.

The results from the study also suggest improved policies for effective documentation of age of the building structure, type of renovations, and occupant energy consumption profile to identify factors that causes variations in household energy consumption for space heating and cooling to develop effective policy measures focusing on specific determinants on energy consumption.

Relevance of this study to policy issues on water heating

The current study identifies mobile homes, race/ethnic category Black, size of the water tank at home, use of dishwasher, preferences in the use of washing machines, total number of rooms, household size and number of heating degree days as potential agents that are associated with the increased energy consumption for water heating. Of these, mobile homes, race/ethnic category Black, size of the water tank, dishwasher and washing machine deserves close attention to enact policy changes in the household energy consumption for water heating.

Size of the water tank is an important in energy consumption for water heating. Bigger the tank size, higher the energy consumption for water heating. Further, on demand 'Tankless water heaters' consume less energy for water heating as compared to conventional storage water heater. Besides the water heater capacity should match the hot water needs of the household. In most cases homebuilders usually decide the type and size of the water heaters. The energy consumption for water heating also differ depending on the type of the fuel used in for water heating and natural gas consumes more energy than electricity to heat the same amount of water. All such factors that influence household energy consumption for water heating make it difficult for the federal government to come up with uniform policies on the minimum energy performance standards for water heaters. Currently, only for conventional storage tank water heating systems, the Energy Guide Label is available. However, local governments may come up with suitable policies, such as creating a partnership with the local builders, creating an energy information center to provide guidance for consumers to make decisions on the purchase of new water heaters. Federal government can also come up with policies, to bring energy star ratings and labeling to various types of water heaters including solar water heaters.

There are continuous developments in the technological front to develop energy efficient and water efficient dishwashers. For example Super Efficient Home Appliances initiative was adopted in 2009 and currently promotes energy efficient dishwasher that use 17% less electricity and 35% less water than the federal minimum (Bansal et al., 2011). However, initial cost might be an issue for the buyers and the intervention by federal and local government in the way of enacting various policies is required to encourage purchases of such modern energy efficient dishwashers. In the RECS sample study for the year 2005, about 78% of the sample was aware of the ENERGY STAR dishwasher (Murray et al., 2011). This indicates that policy shift should be in the direction developing fiscal instruments and in the form of incentives plus tax subsidy measures.

As stated in case of dishwashers, there are recent developments in design of washing machines. Modern washing machines, besides reducing energy consumption, could save 30% of water than the conventional cloth washers (Bansal et al., 2011). However, the barrier for the buyer arises in the form of higher initial cost and policy intervention is needed.

The current study identifies race/ethnic group Black category as the target group for current policy measures in household energy consumption for water heating. Other studies have identified Hispanics and Asians less likely to buy ENERGY STAR washing machines (Murray, 2011). This suggests that federal and local governments need to adopt new policy measures to target information and assistance to these population groups.

CHAPTER TEN: LIMITATIONS OF THIS STUDY

This regression based decomposition method requires identical proximate and socio economic determinants of household energy consumption for each end use i.e. appliance use, space heating, cooling and water heating at two different points in time. These proximate and socioeconomic variables, obtained from the RECS for the years 2001 and 2009 should adhere to same basic definition and similar methods of data collection. Though, the RECS have used the same survey design, the basic categories and some basic definitions have changed in 2009 as compared the year 2001. For example, the rural/urban variable have four different categories in the survey for the year 2001 while the same variable have only two categories in the survey for the year 2009. Therefore, the conclusions drawn on variable rural/urban categories from the regression models and regression based decomposition analysis might have been distorted.

The decomposition method requires the regression models to have the same proximate and socioeconomic determinants at two different points in time to determine the changes in trends in the household energy consumption for each end use and this study is based on the assumption that such determinants remain the same in both the years 2001 and 2009. We also assume that they would not have changed drastically over time to an extent that it distorts the findings from the current study. However, the very determinants of household energy consumption for each end use would have changed in the course of time and the conclusions drawn from the models might not reflect all the relevant changes in the trends in household energy consumption.

The RECS, in each survey, introduces new variables that are relevant to household energy consumption at that point in time. For example, in 1990s cell phones were not widely used in the households in the United States whereas in 2000s every household had on an average four cell phones in their households and it is no different for laptops and computers. Therefore, the small household appliances and new electronic items cannot be included in the current study to determine the trends in the household energy consumption for each end use. This would have slightly altered drawn conclusions from these models.

Among race/ethnic categories for the year 2009, there are about 1.2% respondents who have chosen more than one race/ethnic categories and this group is termed as the mixed race in the survey for the year 2009. Since, their race/ethnic entries spread over the other race/ethnic groups, in the modeling the results drawn on the consumption trends by different race/ethnic groups might have slightly changed.

The regression models in the current study have used the estimates of household energy consumption for each end use by RECS as the outcome variable. This implies that any visible and invisible errors in those estimates would have affected the modeling and the conclusions drawn from the models. Though the RECS estimates are reliable, caution should be exercised while interpreting the conclusions drawn from this study.

APPENDIX: DEFINITIONS

Table 22 Abbreviations and their definitions

Variables	Definition
RECS	Residential Energy Consumption Survey
EIA	Energy Information Administration of the United States
DOE	Department Of Energy
EER	Energy Efficiency Rating
SEER	Seasonal Energy Efficiency Rating

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