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Explaining Residential Energy Consumption: A Focus on Location and Race Differences in Natural Gas Use

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EXPLAINING RESIDENTIAL ENERGY CONSUMPTION: A FOCUS ON LOCATION AND RACE DIFFERENCES IN NATURAL GAS USE*

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ABSTRACT

Researchers have long considered factors related to residential energy consumption. We contribute to this genre of work by exploring how residential location (rural-urban) and race are related to residential natural gas consumption. We also consider whether these relationships, if they exist, are functions of differences in housing characteristics, investment in energy efficiency, and weather conditions. Analyzing four waves of the Residential Energy Consumption Surveys, we find that natural gas consumption differs by residential location only to the extent that investment in energy efficiency and weather conditions are not taken into consideration. We also find race differences in natural gas consumption, with African-Americans consuming more per year than whites. African-Americans' higher natural gas consumption persists even after the effects of housing characteristics, investment in energy efficiency, weather conditions, and other critical covariates of energy consumption are statistically held constant. More work, especially field research, is needed to understand why African-Americans consume more natural gas than other groups.

There has been a long-standing research interest in factors related to U.S. energy consumption (see for example, Adua 2010; Becker et al. 1981; Cramer et al. 1984; Hackett and Lutzenhiser 1991; Herring 2000; Klein et al. 1984; Lutzenhiser 1993; Moezzi 2000; Newman and Day 1975; Perlman and Warren 1977; Poyer and Teotia 1982; Seligman et al. 1979; and Throgmorton and Benard III 1986). Although largely unstated, an important assumption in these studies has been that understanding factors that influence energy consumption constitutes a bridge toward reducing the country's energy consumption and vulnerability to foreign

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energy suppliers. The earlier studies were sparked, in part, by the Arab oil embargoes of 1967 and 1973.

While this genre of studies is extensive, most prevalent when the nation is experiencing an energy "crisis," one important social variable that has received little attention is residential location. Rural-urban differences in housing characteristics (U.S. Census Bureau 2000; U.S. Department of Energy/Energy Information Administration 1995, 1999) and environmental factors (such as the built environment in rural places being less dense) may produce differences in energy consumption. Thus, we ask and address the following questions: 1) Does energy (natural gas) consumption differ by residential location (i.e., rural-urban residence)?; and 2.) If differences do exist, are they explained by differences in housing characteristics, investment in energy efficiency, and environmental factors? Another important variable that has received little attention in the literature is race. A few studies, though, have reported conflicting findings on the relationship between race and energy consumption (Adua 2010; Newman and Day 1975; Poyer and Teotia 1982; and Throgmorton and Benard III 1986). For example, Throgmorton and Benard III (1986) reported the surprising finding of blacks exceeding whites in energy consumption, contrary to previous studies that found the opposite (see Newman and Day 1975). Also, a recent study involving U.S. households showed that whites consume less natural gas than nonwhites (Adua 2010). These findings are intriguing enough to warrant follow-up investigation, given that minority groups often have more limited access to many resources (Caplovitz 1963; Duncan, Featherman, and Duncan 1972; Edwards and Ladd 2000; and Newman and Day 1975). We follow up on this theme of research, asking the following questions: 3) Does energy (natural gas) consumption differ by race?; and 4) If energy consumption does vary by race, to what extent can this be explained by variations in housing characteristics, investment in energy efficiency, and environmental factors.

This paper contributes to an ongoing debate in energy-related research, which has focused on the extent to which physical characteristics of buildings and investment in energy efficiency impact energy consumption/conservation. Two major views have emerged from this debate: the physical-technical-economic models (PTEM) and the lifestyle and social-behavioral tradition (Adua 2010; Brown et al. 1998; Herring 2000; Kempton and Montgomery 1982; Levine et al. 1995; Lutzenhiser 1993; Moezzi 2000; Olsen 1985; Rudin 2004; Schipper 1991; Schipper and Grubb 2000; Starr, Searl, and Alpert 1992; Tommerup, Rose, and Svendsen

2007). The PTEM[1] tradition contends that the physical characteristics of buildings, efficiency improvement in energy conversion and use, and economic and environmental factors are integral to understanding and managing energy consumption. However, the lifestyle and social-behavioral tradition questions this view, contending that these factors alone can only offer minimal explanation of energy consumption in the built environment. These two research traditions emerged, in part, as responses to energy crises in the past (Adua 2010). The present study directly contributes to this debate by empirically investigating whether differences in housing characteristics, investment in energy efficiency, and weather conditions help account for location (rural-urban residence) and race differences in residential natural gas consumption. At the practical level, results of this research can contribute to policy formulation aimed at reducing higher energy (natural gas) consumption among some demographic subpopulations in the country.

EXPLAINING DIFFERENCES IN RESIDENTIAL ENERGY CONSUMPTION

Physical-Technical-Economic Tradition (PTEM)

The physical-technical-economic models (PTEM) represent one broad set of the research frameworks that have emerged to explain energy consumption (or conservation) in the built environment (Brown et al. 1998; Goodacre, Sharples, and Smith 2002; Levine et al. 1995; Olsen 1985; Santamouris et al. 1996; Schipper and Grubb 2000; Starr et al. 1992; and Tommerup et al. 2007). This tradition, which has dominated energy consumption/conservation research in the last several decades, assumes that changes in energy demand result directly from changes in buildings and equipment characteristics as well as economic and environmental factors (see Lutzenhiser 1993). Understanding energy consumption in the built environment, therefore, requires a focus on and analysis of these factors. From this standpoint, the contention is that any observed differences in energy consumption among subgroups in the population essentially come down to differences in these factors.

An important feature of the PTEM tradition is that it assigns only a limited role to the human occupants of buildings (Lutzenhiser 1993). In this tradition, the primary role of humans is 'rationally' responding to energy costs and the associated opportunities, such as investing in technologies that improve energy use efficiency. This tradition presents response to energy prices and self-interested economic rationalization as the primary human-related factors worthy of consideration in

[1] The naming of this tradition as "physical-technical-economic models" was proposed by Lutzenhiser (1993).

energy research and modeling. Starr et al. (1992), for instance, suggested that cost considerations are the 'magic bullet' when it comes to energy conservation (via efficiency improvement and modifying consumer habits). In this tradition, little attention is given to energy use behaviors and patterns that may be associated with social, cultural, and psychological factors (see Lutzenhiser 1993; Lutzenhiser, Harris, and Olsen 2002; and Schipper 1991).

Based on the PTEM analytic tradition, any observed differences in energy consumption by residential location and race would be considered functions of variations in housing characteristics, energy efficiency, energy costs, and environmental factors. Throgmorton and Benard III (1986), for instance, attributed white-black differences in energy consumption to differences in the characteristics of dwelling places of these groups and energy-saving capital investment. Environmental factors, such as geographic location and weather conditions, would also influence differences in energy consumption by residential location and race.

In support of the PTEM research tradition, there is evidence that housing characteristics, energy efficiency improvements, and economic and environmental factors do influence energy consumption in the built environment (Adua 2010; Lutzenhiser 1993; Lutzenhiser and Hackett 1993; Schipper and Grubb 2000; Starr et al. 1992; Tommerup et al 2007; and U.S. Department of Energy 1992). Lutzenhiser and Hackett (1992), for example, reported a negative relationship between efficiency improvement in energy use in buildings (building codes requiring energy efficiency at the time of construction or subsequent conservation improvement) and energy consumption. A report issued by the U.S. Department of Energy (1992) also showed that home retrofits to shell efficiency and new home shell efficiency respectively accounted for 20 and 10 percent of the four quadrillion BTU of delivered residential energy saved. It is important to note, however, that efficiency improvement does not always lead to reduced energy consumption (Adua 2010; Binswanger 2001; and Khazzoom 1987). Adua (2010), for instance, reported a positive relationship between home insulation and electricity consumption. In terms of the impacts of environmental conditions, Adua (2010) found a positive relationship between heating degree days (a measure of heating that may be required) and natural gas consumption. This author also reported a positive relationship between cooling degree days (a measure of cooling that may be required) and electricity consumption.

Given the above-described evidence supporting the central argument of the PTEM tradition, there is a need to further examine whether housing characteristics, energy efficiency improvement, and economic and environmental factors do, indeed, influence any observed location (rural-urban residence) and race differences in natural gas consumption. The question is whether location and race differences in energy consumption will persist if the effects of these factors are taken into account.

Lifestyle and Social-Behavioral Tradition (LSB)

An alternative to the PTEM approach is the lifestyle and social-behavioral tradition (LSB). This tradition draws attention to the importance of human occupants of buildings in explaining energy consumption (or conservation) (Adua 2010; Herring 2000; Lutzenhiser 1993; Moezzi 2000; Rudin 2004; Schipper 1991; Schipper et al. 1989; Stern 1986). The LSB tradition considers how social (noneconomic), behavioral, cultural, and lifestyle factors may be related to energy consumption in the built environment. Schipper et al. (1989:275) have argued "…that changes in the patterns of consumers' activities, which we call life-style, can lead to substantial changes in energy use, particularly in the very long run, even with little change in energy prices or incomes." The LSB tradition contends that without adequate attention to these socio-cultural and behavioral factors, researchers' attempts to explain energy consumption in the built environment may only achieve minimal success.

While this tradition does not deny the role that housing characteristics, investment in energy efficiency, energy costs, and environmental factors play in determining energy consumption in the built environment, it indicts the PTEM tradition for assigning only token importance to human occupants of buildings (Hackett and Lutzenhiser 1991; Lutzenhiser 1994; Schipper 1991; Schipper et al. 1989; Stern 1986). For example, Lutzenhiser (1994) charged that human occupants of buildings are, unfortunately, subsumed by the built environment under the PTEM tradition. In his view, the PTEM tradition assumes homogeneity for all humans, which ignores evidence that energy use behaviors and variability are socially-structured. Also critical of some analysts' fixation on nonhuman aspects of energy modeling, Schipper (1990)[2] argued for better analysis of human behavior, observing that "…those of us who call ourselves energy analysts have made a mistake…we have analyzed energy. We should have analyzed human behavior" (quoted in Cherfas 1991: 156)

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[2]Schipper made this statement during an International Workshop on "Limiting the Greenhouse Effect: Options for Controlling Atmospheric CO2 Accumulation" held from December 10-14, 1990 in Berlin. It was dubbed the Dahlem Workshop.

Based on the LSB tradition, observed differences in energy consumption by residential location and race are expected to be functions of not only differences in factors associated with the PTEM tradition (that is, housing characteristics, investment in energy efficiency, energy costs, and environmental factors), but also of social (noneconomic), behavioral, cultural, and lifestyle factors. This view is succinctly encapsulated in Schipper et al.'s (1989:317) conclusion that "[r]esearch concerned with understanding plausible levels of future energy demand should turn to understanding what people will do and where they will do it."

Is this alternative approach supported by empirical evidence? There is evidence that lifestyle and social and behavioral factors do substantially influence energy consumption in the built environment (Adua 2010; Cramer et al. 1984; Lutzenhiser and Hackett 1993; Mazur and Rosa 1974; Nader and Beckerman 1978; Schipper 1991; Schipper et al. 1989; and U.S. Department of Energy 1992). Mazur and Rosa (1974), for instance, reported a positive relationship between several indicators of lifestyle and energy consumption. A report issued by the U.S. Department of Energy showed that space heating behavior changes (adjusting thermostat settings and closing off unused living areas) accounted for 25 percent of the four quadrillion BTU of delivered energy saved in the residential sector in 1986. This is 5 percent higher than the quantity saved from home retrofits to shell efficiency. A more recent study reported a positive relationship between lifestyle (ownership and use of luxury goods, in this case, a heated swimming pool) and energy consumption, holding constant the effects of efficiency improvement in energy use and other germane covariates of energy consumption (Adua 2010).

The empirical evidence presented above suggests that including lifestyle and social-behavioral variables in energy models might help account for any observed location and race differences in natural gas consumption. While we do not directly consider the influence(s) of these factors in our models, we are still able to assess the claim by the LSB research tradition that fixation on physical aspects of buildings does not adequately account for energy consumption in the built environment. Again, the basic question is whether including indicators associated with the PTEM tradition will eliminate or substantially cut any observed location and race differences in natural gas consumption.

THE INFLUENCES OF RESIDENTIAL LOCATION AND RACE ON ENERGY CONSUMPTION

While studies that have investigated factors related to energy consumption in the built environment are extensive, there is a scarcity of literature specifically considering the influences of residential location and race. The few studies that have considered these variables have not been cumulative. Also, these studies are considerably old. This is partly a reflection of sociologists' marginal and only episodic interest in the subject of energy over the last several decades. Nonetheless, we briefly review the available literature on the impacts of residential location and race on energy use.

The research verdict on the relationship between residential location and energy consumption is mixed (Grier 1977; Heberlein, Fuguitt, and Rathbun 1985; and Zelinsky and Sly 1981). Based on analysis of expected consumption patterns for various households, Zelinsky and Sly (1981) estimated that residential energy consumption was 13 times higher in nonmetropolitan areas than in metropolitan areas in 1960 and 10 percent higher ten years later (i.e., 1970). Focusing on low-income households, Grier (1977) also reported that those residing in nonmetropolitan areas used considerably more natural gas than the average low-income household. In fact, the energy consumption of this group (low-income households in nonmetropolitan areas) approached "the average amount for all U.S. households regardless of income" (Grier 1977:70).

Citing surveys conducted by the U.S. Department of Energy, Heberlein et al. (1985), however, reported energy consumption patterns that contradicted the above findings. These surveys, which were conducted several years later, showed that households residing in urban places consumed slightly more energy than inhabitants of rural places. Heberlein et al. (1985), however, acknowledged that these differences were not necessarily significant. Whether significant or not, this finding still betrays a lack of support for the earlier ones. If the differences are significant, the latter studies would suggest that rural residents use less energy than urban residents, directly contradicting the earlier findings of Grier (1977) and Zelinsky and Sly (1981). However, if the differences are not significant, it will simply mean that the latter studies do not corroborate the findings of the earlier ones. One potential reason Herberlein et al.'s (1985) finding is not consistent with the previous ones is that the relationship between residential location and energy consumption may have simply changed over time.

Similar to residential location, few studies have considered the relationship between race and energy consumption. These studies generally suggest the relationship may be mixed (Adua 2010; Klein et al. 1984; Newman and Day 1975; Poyer and Teotia 1982; Throgmorton and Benard III 1986). In a seminal study titled *The American Energy Consumer*, Newman and Day (1975) reported a negative relationship between belonging to a minority racial group (black) and total energy consumption. According to these authors, the average black household used about 250 million Btu's of energy (electricity, natural gas, and gasoline) between 1972 and 1973, 25 percent less than other households. Restricting the analysis to residential energy consumption only, Newman and Day reported that black households averaged 200 million Btu's of electricity and natural gas compared with 238 million Btu's for other households. Consistent with Newman and Day's finding, Adua (2010) also reported that white households consumed significantly more electricity than nonwhites.

In contrast, other studies reported positive relationships between being a minority person/household, especially black, and energy consumption (Klein et al. 1984; Poyer and Teotia 1982; Throgmorton and Benard III 1986; U.S. Department of State/Energy Information Administration 1999). In a review study of minorities and energy consumption, Throgmorton and Benard III (1986:274), for instance, proclaimed that "whereas black households used to consume less energy for residential or transportation purposes than did whites, they now consume more." Taking into account home ownership status, housing type (single versus multi-family units), and the effects of climate, Throgmorton and Benard III (1986) reported that black households consumed substantially more natural gas than white households. For example, between 1981 and 1982, black renter-households consumed 21,100 Btu's of natural gas compared with 14,000 for white renter-households. The authors attributed these findings to differences in energy-saving capital investments. Also, a report issued by the U.S. Department of Energy/Energy Information Administration (1999) shows that black households consume more energy than white and other households. The inconsistencies in findings related to differences in overall energy consumption by race perhaps result from the fact that energy consumption patterns for the various groups, especially blacks relative to whites, have changed over time.

This brief review of the empirical literature suggests that the relationships between residential location (rural versus urban setting) and race on the one hand and energy consumption on the other are mixed. Since most of these studies were conducted several years (decades) ago and do not account for the impacts of other critical covariates of energy use, the question is whether differences in energy consumption by residential location and race persist. We consider these relationships by assembling and analyzing national energy consumption data collected in 1993, 1997, 2001, and 2005.

EXPECTED RELATIONSHIPS

Based on our review of the extant literature, we expect significant rural-urban differences in residential natural gas consumption. We also expect significant race differences in natural gas consumption. Also, based on our reading of the PTEM research tradition and the associated empirical evidence, we expect indicators of efficiency improvement in energy use, housing characteristics, and weather conditions to be strongly related to residential natural gas consumption. As discussed above, empirical evidence supports the existence of these relationships (Adua 2010; Lutzenhiser 1993; Lutzenhiser and Hackett 1993; Olsen 1985). We anticipate that these indicators will help explain any observed rural-urban and race differences in natural gas consumption. However, as suggested under the LSB research tradition, we expect the role these indicators play in explaining these differences in natural gas consumption to be minimal.

DATA AND MEASURES

The data used in this study come from the Residential Energy Consumption Surveys (RECS) conducted by the Energy Information Administration (EIA) of the U.S. Department of Energy. The EIA describes the RECS as national area-probability sample surveys that collect data on occupied housing units in the United States, focusing on households.[3] The data come from a combination of three sources: 1) in-person interviews with householders of sampled housing units; 2) completed mail questionnaires from, or in-person or telephone interviews with, rental agents for sampled rental units in which part or all energy costs were included in the rent; and 3) completed mail questionnaires from energy suppliers who provided actual energy consumption and expenditure information for the sampled housing units.

According to EIA documentation, the RECS implement two major strategies to address the challenge of nonresponse bias (that is, unit and item nonresponse).[4] First, the base sampling weights, which we use in our analysis, adjust for nonresponse bias. This procedure directly addresses the problem of unit nonresponse. To address the second source of potential nonresponse bias – item nonresponse – missing cases were appropriately imputed. Imputation involves

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[3] Detailed information about the RECS and the microdata for the specific surveys used in this paper is available at http://www.eia.doe.gov/emeu/recs/recspubuse05/pubuse05.html.

[4] Unit nonresponse is used in survey research to mean complete failure to obtain measurements from one or several sampled units, while item nonresponse denotes failure to obtain measurement on one or more items in a survey (questionnaire).

replacing missing values with estimated responses (Groves et al. 2004). Appendix A shows all the variables used in this study that had imputed values.

For this study, we use the 1993 (N=7,111), 1997 (N=5,900), 2001 (N=4,822) and 2005 (N=4,382) RECS. We combined these surveys (data sets) for variables that were comparably measured across the four times to create a pooled cross-sectional dataset (N=22,215 households). The pooled sample is used for some of the multivariate analyses reported. Statistics showing the distribution of the sample for variables used in this study are shown in Tables 1, 2, and 3.

TABLE 1. DESCRIPTIVE STATISTICS FOR NATURAL GAS CONSUMPTION, RESIDENTIAL LOCATION, AND RACE (STANDARD DEVIATIONS IN PARENTHESES)

	1993	1997	2001	2005
Cubic Feet of Natural Gas				
Consumed Annually.	869.3	813.0	715.6	700.5
	(569.5)	(558.7)	(469.8)	(460.7)
Residential Location				
City.	57.2%	59.6%	52.8%	50.3%
Town.	15.2%	17.5%	17.1%	20.1%
Suburbs.	22.3%	17.2%	18.2%	22.1%
Rural.	5.3%	5.7%	11.9%	7.5%
Race				
White.	78.5%	70.4%	73.7%	68.9%
Black.	15.0%	15.8%	13.6%	13.4%
Native American.	0.4%	1.0%	0.7%	1.0%
Asian American.	3.2%	3.2%	3.3%	3.9%
Other.	0.2%	1.2%	1.7%	6.2%
Hispanic.	2.6%	8.3%	7.1%	6.5%

NOTE: Reported statistics for residential location and race are for only respondents who use natural gas

Dependent Variable

The main dependent variable in this study is residential natural gas consumption, measured by actual annual natural gas usage within a household (cubic feet). This information was obtained from respondents' utility service providers. Respondents granted permission for this information to be accessed from their utility providers. Respondents who did not use natural gas in their homes were recoded as missing in the sample. Descriptive statistics for this variable are shown in Table 1.

Independent Variables

We operationalized six sets of independent variables: residential location; race; housing characteristics; investment in energy efficiency; weather conditions; and other empirically germane statistical control variables.

Residential Location. Residential location is measured by whether a responding household's place of residence is located in a city, a town, a suburb, or a rural place. Respondents were asked: "Which of the following best describes the location of your home? Do you live in a city, a town, the suburbs, or in a rural area?"[5] While there is no one standard conceptualization of rurality (Jones, Fly, and Cordell 1999), this question generates data that allow us to assess how residents of relatively more rural places compare with those of more urban settings (especially cities) in natural gas consumption. Descriptive statistics for residential location are shown in Table 1.

Race. We measured race by respondents' self-identified racial affiliation. These are: white; black (i.e., African American); Native American (i.e., American Indian or Alaskan Native); Asian American (i.e., Asian, Hawaiian, or Pacific Islander); Hispanic (if volunteered); and others (if volunteered). While racial categories are considerably hard to define, this item has been used over the years in the RECS to provide accurate, nationally-representative, energy-related information for the groups identified here. We recognize that the Hispanic category is more of an ethnic characterization than race. Nevertheless, we leave it as a category in our measure of race to not lose cases. Descriptive statistics for race are reported in Table 1.

Housing Characteristics. We measured housing characteristics (see Table 2) by the age of a respondent's home (the number of years since a home was built); size of the home (number of bedrooms and home square footage); and type of home (detached single-family unit, attached single-family unit, or multiple-family unit of two or more apartments).

Investment in Energy Efficiency. We used several indicators to measure investment in energy efficiency. The first indicator measures the overall extent to which a respondent's place of residence is insulated. Respondents were asked in the survey: "Overall, would you say that this home/apartment is well insulated, adequately insulated, or poorly insulated."[6] The response options included: 1 (well

[5] This is not inconsistent with previous studies that measured residential location by respondents' own self-reports (Huddart-Kennedy et al. 2009; Sharp and Tucker 2005).

[6] Interviewers provided clarification on what this means, including noting that insulation included window caulking and weather stripping.

TABLE 2. DESCRIPTIVE STATISTICS FOR HOUSING CHARACTERISTICS (STANDARD DEVIATIONS IN PARENTHESES)

INDICATORS	1993	1997	2001	2005
Age of home.	10.5	13.0	9.9	9.2
	(3.4)	(2.9)	(2.7)	(2.9)
Number bedrooms.	2.6	2.7	2.7	2.8
	(1.0)	(1.0)	(1.0)	(1.1)
Home square footage.	1949.6	1646.8	2103.7	2347.4
	(1300.3)	(883.6)	(1443.6)	(1630.0)
Type of home:				
Detached single-family unit.	64.1%	65.9%	62.2%	67.5%
Attached single-family unit.	8.7%	11.4%	10.9%	10.0%
Apartment building with two or more units.	27.2%	22.7%	27.0%	22.6%

insulated), 2 (adequately insulated), 3 (poorly insulated), and 4 (no insulation). The fourth response was volunteered by the respondents. We reverse-coded these response options for the analyses reported in this paper. The second indicator of energy efficiency is whether or not a household's main heating system uses a thermostat to adjust the temperature during the heating season. The last set of energy efficiency indicators is: whether or not the outside walls of a respondent's home, water heater, and pipes that carry hot water within the home are insulated; whether or not a home's heating equipment is regularly maintained; the type of glass in sliding doors (single pane, double pane, double pane with low-e[7], triple pane, and triple pane with low-e); and the type of glass in most windows in the home. This latter set of indicators is only available for the 1993 sample. Descriptive statistics for these measures are reported in Table 3.

Weather Condition. Because the PTEM research framework considers environmental factors as integral to energy analysis, we used heating degree days (HDD) as a measure of geographic differences in weather conditions. Heating degree days are the number of days the average daily temperature is below the base temperature of 65. According to the Energy Information Administration, the HDD

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[7] Low-e stands for low-emissivity. These are coated glasses that can regulate how much heat (energy) a building gains or loses. Prior to being asked about the type of glass used, respondents were asked if they were aware of low-e glasses. Interviewers also used exhibits to help respondents accurately identify the various types of glasses.

TABLE 3. DESCRIPTIVE STATISTICS FOR INVESTMENT IN ENERGY EFFICIENCY (STANDARD DEVIATIONS IN PARENTHESES)

Indicators	1993	1997	2001	2005
Adequacy of home insulation:				
Not insulated.	1.5%	0.7%	0.8%	1.3%
Poorly insulated.	21.1%	21.5%	21.3%	19.9%
Adequately insulated.	39.8%	44.6%	40.8%	42.1%
Well insulated.	37.7%	33.3%	37.2%	36.8%
Heating system has thermostat.	83.5%	82.3%	85.4%	88.1%
Outside wall insulated?				
No.	11.7%	-	-	-
Yes.	50.3%	-	-	-
Don't know/not applicable.	37.9%	-	-	-
Hot water heater insulated? No.	53.9%	-	-	-
Yes.	15.7%	-	-	-
Don't know/not applicable.	30.4%	-	-	-
Hot water pipes insulated?				
No.	43.4%	-	-	-
Yes.	21.3%	-	-	-
Don't know/not applicable.	35.2%	-	-	-
Regular maintenance of heating equipment? (Yes=1).	52.3%	-	-	-
Type of glass sliding door used:				
Single pane.	10.6%	-	-	-
Double pane.	17.2%	-	-	-
Double pane w/low-e, triple pane, triple pane w/low-e.	1.3%	-	-	-
Not applicable.	70.9%	-	-	-
Type of glass in most windows:				
Single pane.	60.9%	-	-	-
Double pane.	36.0%	-	-	-
Double pane w/low-e, triple pane, triple pane w/low-e.	3.1%	-	-	-
Heating degree days.	4735.9	4516.1	4243.4	4444.2
	(2311.8)	(2229.7)	(1922.6)	(2086.2)

values reported were based on data obtained from the National Oceanic and Atmospheric Administration (NOAA). The EIA's survey documentation also reports that a random error was added to the values of this variable to conceal the location of the weather station from which they were obtained.

Statistical Controls. In our multivariate models, we statistically controlled for the effects of several variables shown in previous studies to influence energy consumption. These are: type of fuel used for cooking; type of fuel used for space heating; type of fuel used for heating water; home ownership; household pretax income for the twelve months preceding the survey;[8] number of persons living in the household; whether someone is always at home; sleeping hours temperature during winter; and whether a household received heating aid in the previous year (Adua 2010; Klein et al. 1984; Lutzenhiser 1993; Lutzenhiser and Hackett 1993;O'Neil and Chen 2002; Ritchie et al. 1981; and Schipper et al. 1989). Sample descriptive statistics for this set of variables are shown in Table 4.

ANALYSIS

In this section, we present bivariate and multivariate models showing how residential location and race are related to natural gas consumption. We also present bivariate results of how these variables (residential location and race) are related to some indicators of two other variables hypothesized to mediate residential energy consumption – housing characteristics and investment in energy efficiency (see Newman and Day 1975; Throgmorton and Benard III 1986). For the bivariate relationships, we report both ANOVA results and cross-tabs (see Tables 5, 6, 7, and 8). The multivariate analyses include several fixed effects and ordinary least-squares (OLS) regression models (Tables 9 and 10).

ANOVA Results of Natural Gas Consumption by Race and Residential Location

The ANOVA results reported in Table 5 indicate that residential natural gas consumption varies by residential location. The analysis shows that rural residents consumed more natural gas in 1993 than the other residential categories. In 1997 and 2001, however, residents of suburbs topped rural residents in natural gas consumption. In 2005, residents of suburbs and towns were virtually tied at the top in natural gas use. It is evident from Table 5 that the relationship between residential location and natural gas consumption has not followed a consistent pattern across the four samples. It is unclear why this is the case. Nevertheless, the relationship has been consistently significant for all four samples.

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[8]The original response options for income were not comparable across all four waves of the survey. To make the options comparable, we first recoded each response option to its category midpoint. We next converted respondents' nominal 1997, 2001, and 2005 dollar incomes into 1993 real dollars. This adjusted for inflation (see similar coding and adjustment of this variable, as reported in the RECS data, in Adua 2010).

TABLE 4. DESCRIPTIVE STATISTICS FOR WEATHER AND STATISTICAL CONTROL VARIABLES (STANDARD DEVIATIONS IN PARENTHESES)

INDICATORS	1993	1997	2001	2005
Fuel used for cooking:				
Natural gas.	53.4%	52.3%	42.9%	56.1%
Electricity.	46.6%	47.7%	54.0%	43.6%
Other fuels.	0.0%	0.0%	3.1%	0.3%
Fuel used for space heating:				
Natural gas.	87.2%	85.5%	69.3%	85.9%
Electricity.	6.0%	7.7%	18.7%	9.3%
Other fuels.	6.6%	6.9%	12.0%	4.9%
Fuel used for heating water:				
Natural gas.	87.1%	83.8%	68.0%	85.9%
Electricity.	9.7%	11.9%	25.8%	12.2%
Other fuels.	3.2%	4.4%	6.3%	1.9%
Home ownership (own=1).	63.7%	65.3%	67.5%	67.9
Real income (1993 dollars).	35744.1	32501.0	36084.4	36900.3
	(26705.0)	(24443.2)	(23275.3)	(26515.0)
Number of household members.	2.7	2.7	2.7	2.7
	(1.5)	(1.5)	(1.5)	(1.5)
Member at home always? (yes=1).	48.0%	52.%	51.3%	53.1%
Sleeping hours temperature in winter.	67.3	67.4	67.5	68.2
	(5.2)	(5.6)	(5.4)	(5.5)
Received heating aid?				
No.	46.3%	42.6%	40.1%	-
Yes.	3.6%	3.7%	4.0%	-
Not applicable/refused.	50.2%	53.8%	56.0%	-

The ANOVA models shown in Table 5 also indicate that residential natural gas consumption differs by race across all four samples. The data consistently show that African-Americans consume more natural gas than all other groups (white; American Indian or Alaskan Native; Asian, Hawaiian, or Pacific Islander; Hispanic; and others). Are these differences significant? Bonferroni multiple-comparison tests (not reported in the tables) show that African-Americans significantly differed from one or more of the other groups in natural gas consumption across the four samples.

This represents a de facto multiple-sample validation of African-Americans' higher natural gas consumption compared with other groups.

TABLE 5. ANOVA RESULTS FOR HOUSEHOLD NATURAL GAS CONSUMPTION BY RESIDENTIAL LOCATION AND RACE

	Household Natural Gas Consumption (cubic feet)			
	1993	1997	2001	2005
Residential Location				
City	816.6	770.6	685.3	660.2
Town	873.9	851.9	739.5	750.8
Suburbs	961.4	907.9	783.1	749.6
Rural	1038.9	850.4	712.5	691.8
Between Group F-Test (df=3)	21.2***	11.1***	6.3***	7.9***
Race				
White	880.5	848.1	733.5	722.2
Black	940.5	896.1	812.8	746.5
Native American	737.3	716.9	613.9	630.0
Asian American	598.4	585.5	505.3	573.7
Other	436.2	628.7	482.5	521.3
Hispanic	523.6	482.8	505.8	637.4
Between Group F-Test (df=5)	17.6***	30.5***	19.4***	9.2***

Are the differences reported in the above ANOVA models due to differences in housing characteristics, investment in energy efficiency, and weather conditions? Before addressing this question, we need to first establish whether housing characteristics and investment in energy efficiency, indeed, differ by residential location and race. Thus, we present several bivariate models showing the relationships between residential location and race on the one hand and several indicators of housing characteristics and investment in energy efficiency on the other.

Variations in Housing Characteristics by Residential Location and Race

The bivariate relationships between residential location and race and some indicators of housing characteristics are shown in Table 6. All the models reported show that housing characteristics do vary by residential location and race. In terms of home type, for instance, inhabitants of rural places are significantly more likely to live in detached single-family housing units than inhabitants of suburbs, towns, and cities. For home age, the data show that residents of cities are consistently more likely to reside in older homes than those of towns, suburbs, and rural places. In terms of race, the data show that whites are significantly more likely to reside in detached singe-family housing units than the other groups. The 1993 sample shows that African-Americans are more likely to reside in older homes than the other groups. However, in the 2005 sample, African-Americans were supplanted by Hispanics as the group more likely to reside in older homes.

TABLE 6. VARIATIONS IN HOUSING CHARACTERISTICS BY RESIDENTIAL LOCATION AND RACE, 1993 AND 2005

	1993			2005		
	HOME AGE	BDRMs	SQ. FT.	HOME AGE	BDRMs	SQ. FT.
Residential Location:						
City.........	10.6	2.4	1634.1	9.4	2.5	1877.4
Town.	10.5	2.7	1919.4	9.4	2.7	2281.9
Suburbs.	8.8	2.9	2279.5	8.1	3.1	2896.1
Rural.	9.3	3.0	2257.3	8.2	2.9	2583.8
Between Group Variance F-test (df=3).	122.3***	134.4***	133.7***	66.8***	73.4***	94.1***
Race:						
White...........	9.9	2.7	2046.6	8.8	2.8	2452.7
Black.	10.9	2.5	1390.3	9.1	2.5	1934.0
Native Amer.	10.2	2.5	1163.6	8.9	2.7	1508.2
Asian Amer..	10.1	2.4	1467.9	8.7	2.7	1887.8
Other.	10.7	1.7	911.7	9.2	2.6	2004.4
Hispanic.	10.4	2.0	1125.6	9.3	2.5	1653.6
Between Group Variance F-test (df=5).	13.6***	25.8***	65.5***	2.7*	11.2***	26.1***

NOTE: Except those specified as percentages or test statistics, all statistics reported in this Table are means.

TABLE 6. VARIATIONS IN HOUSING CHARACTERISTICS BY RESIDENTIAL LOCATION AND RACE, 1993 AND 2005 (*Continued*)

	1993			2005		
	Apt. bldg.	Attached single-family	Detached single-family	Apt. bldg.	Attached single-family	Detached single-family
Residential Location:						
City.........	2.8%	47.1%	50.1%	3.9%	44.5%	51.6%
Town.	5.3%	24.5%	70.2%	4.0%	28.0%	68.0%
Suburbs.	3.3%	29.0%	67.8%	2.6%	22.2%	75.2%
Rural.	17.4%	5.4%	77.2%	16.7%	3.6%	79.8%
Design-based test.........	$F(6.0, 42464.1)^a = 136.5^{***}$			$F(6.0, 26264.0)^a = 94.5^{***}$		
Race:						
White...........	6.4%	28.1%	65.5%	7.0%	22.8%	70.2%
Black.	2.3%	54.9%	42.8%	4.2%	46.0%	49.9%
Native Amer.	18.1%	35.7%	46.1%	12.9%	24.3%	62.8%
Asian Amer.	0.2%	55.6%	44.2%	0.0%	47.1%	52.9%
Other.	0.0%	80.1%	20.0%	2.8%	35.9%	61.3%
Hispanic.	5.4%	58.1%	36.5%	7.0%	50.0%	43.0%
Design-based test.........	$F(9.5, 67432.3)^a = 30.0^{***}$			$F(9.9, 43537.1)^a = 21.4^{***}$		

[a] These test statistics are actually Rao-Scott corrected chi-squared statistics (second-order correction) that have been converted into F statistics (see Rao and Scott 1984). The Rao-Scott second-order correction of chi-squared statistics adjusts for survey design.

Variations in Energy Efficiency Investment by Residential Location and Race

In Tables 7 and 8, we report the bivariate relationships between residential location and race on the one hand and investment in energy efficiency on the other. Analyses based on the 1993 and 2005 samples show that several indicators of investment in energy efficiency vary by residential location and race. These include: overall home insulation; ownership and use of a thermostat-fitted heating system; insulation of outside walls; and type of glass in most windows (single pane, double pane, double pane with low-e, triple pane, and triple pane with low-e). For example, the data indicate that rural residents are more likely to report that their homes are well insulated. Inhabitants of rural locations are also more likely to report that the outside walls of their homes are insulated.

TABLE 7. VARIATION IN INDICATORS OF ENERGY EFFICIENCY INVESTMENT BY RESIDENTIAL LOCATION AND RACE

	1993			2005		
	Adequacy of home insulation			Adequacy of home insulation		
	None or poor	Adequate	Well	None or poor	Adequate	Well
Residential Location						
City..............	25.8%	41.2%	33.1%	21.2%	44.1%	34.7%
Town.	22.5%	37.5%	40.0%	18.3%	43.3%	38.5%
Suburbs.	18.9%	41.3%	39.8%	15.9%	42.2%	41.9%
Rural.	20.6%	36.1%	43.3%	16.0%	38.0%	46.0%
Design-based test...............	F(6.0, 42575.7)[a] = 8.3***			F(6.0, 25802.5)[a] = 5.8***		
Race						
White.................	21.3%	39.8%	39.0%	17.2%	42.1%	40.7%
Black.	30.5%	39.4%	30.2%	23.4%	43.1%	33.5%
Native Amer.	37.6%	35.5%	26.9%	33.4%	44.4%	22.2%
Asian Amer.	30.0%	43.4%	26.7%	17.6%	48.5%	33.9%
Other.	41.9%	27.5%	30.6%	21.2%	40.9%	37.9%
Hispanic.	33.6%	37.5%	28.9%	21.3%	41.1%	37.6%
Design-based test...............	F(9.9, 70090.7)[a] = 5.3***			F(10.0, 42882.2)[a] = 2.4**		
	Heating system has thermostat?			Heating system has thermostat		
	No	Yes	-	No	Yes	-
Residential Location						
City..............	18.5%	81.5%	-	14.8%	85.2%	-
Town.	15.2%	84.8%	-	11.0%	89.0%	-
Suburbs.	7.3%	92.7%	-	5.0%	95.0%	-
Rural.	22.1%	77.9%	-	17.8%	82.2%	-
Design-based test...............	F(3.0, 21131.2)[a] = 34.1***			F(3.0, 12947.9)[a] = 22.6***		
Race						
White.................	14.0%	86.0%	-	9.6%	90.4%	-
Black.	28.0%	72.1%	-	17.9%	82.1%	-
Native Amer....	20.0%	80.1%	-	22.9%	77.1%	-
Asian Amer......	16.2%	83.8%	-	18.6%	81.4%	-
Other.	45.6%	54.4%	-	17.7%	82.3%	-
Hispanic.	46.5%	53.5%	-	30.4%	69.6%	-
Design-based test...............	F(5.0, 35097.8)[a] = 28.4***			F(5.0, 21487.2)[a] = 22.7***		

[a] These test statistics are actually Rao-Scott corrected chi-squared statistics (second-order correction) that have been converted into F statistics (see Rao and Scott 1984). The Rao-Scott second-order correction of chi-squared statistics adjusts for complex survey design.

TABLE 8. VARIATION IN 1993 INDICATORS OF ENERGY EFFICIENCY INVESTMENT BY RESIDENTIAL LOCATION AND RACE

	Outside wall insulated?			Type of glass in most windows		
	No	Yes	DK/ NA	Single pane	Double pane	Double with low-e
Residential Location						
City	11.4%	38.6%	50.0%	68.8%	28.9%	2.3%
Town	13.7%	56.1%	30.2%	69.1%	29.0%	1.9%
Suburbs	11.8%	59.3%	28.9%	54.1%	43.6%	2.3%
Rural	11.2%	78.8%	10.0%	56.1%	39.0%	4.9%
Design-based test	$F(6.0, 42542.8)^a = 90.6^{***}$			$F(6.0, 42344.4)^a = 22.0^{***}$		
Race						
White	11.6%	57.6%	30.8%	62.6%	34.3%	3.0%
Black	12.9%	28.5%	58.6%	69.2%	29.6%	1.2%
Native Amer.	17.5%	31.9%	50.5%	56.2%	43.1%	0.7%
Asian Amer.	13.1%	28.8%	58.2%	68.7%	31.3%	0.0%
Other	8.1%	11.8%	80.1%	81.6%	18.5%	0.0%
Hispanic	13.3%	17.0%	69.7%	69.7%	30.3%	0.0%
Design-based test	$F(9.7, 69229.8)^a = 32.1^{***}$			$F(9.3, 66031.2)^a = 3.0^{**}$		

[a] These test statistics are actually Rao-Scott corrected chi-squared statistics (second-order correction) that have been converted into F statistics (see Rao and Scott 1984). The Rao-Scott second-order correction of chi-squared statistics adjusts for complex survey design.

In terms of race, the data suggest whites are more likely than the other groups to reside in well-insulated homes, while Asians, Hawaiians, and/or Pacific Islanders are the least likely to live in well-insulated homes. Further, whites are more likely to live in homes with insulated outside walls than the other groups. With these differences established, the question is whether they exert any influence on natural gas consumption? We address this question next.

Multivariate Models

Multivariate regression models of natural gas consumption are reported in Tables 9 and 10. We report results from both fixed effects and OLS regression models. The fixed effects models are based on a pooled dataset consisting of the 1993, 1997, 2001, and 2005 RECS samples. Within the combined dataset, we created a new variable that identified the year individual cases were surveyed. Pooling the four samples necessitated the use of an estimation method that takes

TABLE 9. FIXED EFFECTS REGRESSION MODELS OF HOUSEHOLD NATURAL GAS CONSUMPTION, 1993–2005

	Model 1		Model 2		Model 3		Model 4	
	b	S.E.	b	S.E.	b	S.E.	b	S.E.
Residential Location								
Town	44.1**	13.4	38.2**	12.5	-2.9	11.9	-5.0	14.0
Suburbs	6.6	12.4	17.7	12.0	-20.9	10.8	-26.5*	12.7
Rural	64.5**	20.6	67.0**	20.6	19.6	18.7	27.7	22.3
Race								
Black	158.0***	17.0	138.1***	15.9	188.3***	14.5	209.6***	16.7
Native American	-104.8*	46.9	-105.7*	43.4	-66.5	37.3	-51.0	43.4
Asian American	-204.2***	26.7	-156.0***	25.2	-62.7**	21.5	-64.7**	24.9
Other	-146.0***	28.6	-130.1***	27.6	-44.3	24.8	-120.0**	43.4
Hispanic	-155.6***	23.0	-125.1***	23.2	-14.9	20.3	-37.0	21.3
Housing Characteristics								
Age of home			40.6***	1.8	29.7***	1.7	29.5***	1.9
Bedrooms			119.3***	7.9	127.2***	7.4	136.6***	8.6
Square footage			0.1***	0.0	0.1***	0.0	0.1***	0.0
Detached single-family			-110.6***	18.0	-21.7	17.0	-23.7	19.0
Attached single-family			-57.1**	19.4	-39.9*	18.2	-41.6*	20.7
Adequacy of insulation								
Poorly insulated					-55.0	51.6	-36.0	59.2
Adequately insulated					-121.2*	51.3	-112.4	59.0
Well insulated					-126.4*	51.6	-123.2*	59.3
Thermostat					11.8	14.5	20.5	15.9
Heating degree days					0.1***	0.0	0.1***	0.0
Cooking Fuel[a]								
Electricity	-17.9	10.3	-21.8*	9.6	-42.4***	8.8	-37.1***	10.3
Other fuels	272.8***	54.1	329.0***	69.3	322.7***	65.7	405.6***	61.0
Space Heating Fuel[a]								
Electricity	-348.5***	14.3	-301.0***	14.6	-136.8***	14.6	-112.9***	17.5
Other fuels	-443.4***	22.1	-518.9***	24.4	-534.7***	25.3	-520.1***	29.5
Water Heating Fuel[a]								
Electricity	-82.0***	13.3	-70.4***	13.5	-98.6***	12.9	-94.5***	14.9
Other fuels	-119.2***	32.2	-100.8**	33.5	-81.0*	33.0	-70.9	37.3
Own Home	209.2***	10.8	105.6***	13.7	95.5***	12.5	107.6***	14.2
Income (1993 real dollars)	0.0	0.0	0.0	0.0	-0.0*	0.0	0.0	0.0
Income*Income	0.0***	0.0	0.0**	0.0	0.0***	0.0	0.0*	0.0
Number in household	56.2***	4.1	27.6***	4.0	24.7***	3.8	22.1***	4.4
Member at home always	61.4***	10.3	47.0***	9.8	61.5***	8.9	57.4***	10.4
Winter sleeping hours temp.	5.3***	1.0	6.3***	0.9	6.7***	0.8	7.4***	1.0
Received heating aid								
Yes							24.7	31.0
Not applicable							-30.1*	13.4
Intercept	190.5		-560.9		-847.4		-949.6	
N	11272.0		10805.0		10752.0		8506.0	
Grouping Variable Count	4.0		4.0		4.0		3.0	

NOTE: *<.05; **<.01; and ***<.001; [a]The reference category is "natural gas".

into account that individual cases are nested within survey years. The OLS regression models are based on the 1993 RECS sample, which has additional measures of investment in energy efficiency. Although the 1993 data (sample) is somewhat dated, analyzing it still afforded us the opportunity to further understand how investment in energy efficiency helps explain differences in energy consumption among demographic subpopulations in the country. Because the RECS are based on area-probability samples, we conducted weighted analyses to account for households' unequal chances of inclusion in the sample. This also addressed the potential problem of nonresponse bias as the sample weights used adjusted for unit nonresponse. We checked our models for collinearity, interaction effects, and curvilinear relationships. We did not find high enough correlations among our predictors to destabilize the models. We also did not find consistent patterns of interaction effects in the models. Our tests, however, revealed a curvilinear relationship between income and natural gas consumption in the pooled sample. We now present the regression models, starting with the fixed effects models.

Regression models examining how residential location and race are related to natural gas consumption are shown in Tables 9 and 10. Model 1 in Table 9 shows these relationships when the effects of housing characteristics, investment in energy efficiency, and weather conditions are not taken into account.[9] This model reveals quite a strong relationship between residential location and natural gas consumption. The model shows that rural residents consume about 66 cubic feet more natural gas per year than city dwellers. The model also indicates that residents of towns consume significantly more natural gas than those of cities. Model 1 also reveals a very strong relationship between race and natural gas use. The model indicates that African-Americans use about 158 cubic feet more natural gas per annum than whites. The remaining groups in our analysis, however, use significantly less natural gas than whites. For example, American Indians /Alaska Natives use about 105 cubic feet less natural gas per year than whites.

The second model in Table 9 (Model 2) shows how residential location and race are related to natural gas consumption when the effects of housing characteristics, along with the control variables, are held constant. In this model, the relationship between residential location and natural gas consumption remains virtually unaltered. This suggests that rural-urban differences in natural gas consumption may be unaffected by housing characteristics. Consistent with our anticipation, holding constant the effects of housing characteristics slightly moderates the relationship between race and natural gas consumption. For example, while African-Americans continue to consume more natural gas per year than whites, this difference drops from about 158 in Model 1 (that is, before controlling for the

[9]All the models reported in Table 9 and 10 hold constant the effects our control variables.

effects of housing characteristics) to about 138 cubic feet in Model 2 (that is, net the effects of housing characteristics). This finding provides some support for the PTEM research and analytic tradition, which posits that housing characteristics may mediate residential energy consumption. The model reveals sufficiently strong relationships between the indicators of housing characteristics and natural gas consumption (Table 9, Model 2). As an example, a one room difference between homes results in about 119 cubic feet difference in natural gas consumption. Also, a year difference in home age results in about 41 cubic feet difference in natural gas consumption.

In the final two models reported in Table 9 (Model 3 and 4), we consider how residential location and race are related to natural gas consumption, while accounting for the effects of housing characteristics, investment in energy efficiency, weather conditions, and the statistical control variables. The only difference between Model 3 and 4 is that Model 4 is based on three of the four samples (datasets) used in this study. Besides all the variables described above, Model 4 controls for whether or not a respondent/household received heating aid in the previous year. This variable was not available for the 2005 sample.

The relationship between residential location and natural gas consumption disappears once the effects of investment in energy efficiency and weather conditions are held constant (Model 3, Table 9). This is consistent with expectations under the PTEM research tradition. However, once receipt of heating aid is added to the model (Model 4), we find that those residing in suburbs consume less natural gas per year than those residing in cities. This means that the effects of suburban residence on natural gas use may have been suppressed by the absence of this variable – receipt of heating aid – in the model. This suggests that the effect of suburban residence on natural gas consumption may only be revealed when the influence of heating aid receipt is statistically parceled out.

In terms of race, we find that including investment in energy efficiency and weather conditions in the model results in a substantial increase in the difference between African-Americans and whites in natural gas consumption (Table 9, Models 3 and 4). This finding contradicts Throgmorton and Benard III's (1986) thesis that blacks use more energy than whites because of differences in energy-saving capital investment. Not only does this contradict expectations under the PTEM research tradition, it provides support for the LSB. The LSB tradition cautions that exclusive focus on physical housing characteristics and economic and environmental factors will not be sufficient in explaining energy consumption in the built environment. African-Americans continue to use more energy (natural gas) than all other groups in our analyses though we accounted for the effects of these variables. Once the effects of investment in energy efficiency and weather are held constant in Model 3 (Table 9), only respondents who self-identified as 'Asian/Hawaiian/Pacific Islanders' consume less natural gas than whites. In Model 4 (Table 9), where we also control for the influence of heating aid receipt, however, we find that respondents who self-identified as either 'Asian/Hawaiian/Pacific Islander' or 'Other' consume less natural gas than whites. This suggests that the provision of heating aid may have distorted (inflated) energy consumption among these minority groups.

Similar to the results reported in Model 2, the effects of housing characteristics on natural gas consumption in these latter two models (Models 3 and 4 of Table 9) remain considerably strong. The one difference is that respondents who reside in detached single-family housing units no longer differ from those who reside in apartment buildings with two or more units in natural gas consumption. This model also shows some significant relationships between investment in energy efficiency and natural gas consumption. Living in a well-insulated home is, for instance, associated with 126.4 cubic feet less natural gas consumption than living in a home without any insulation (Model 3, Table 9). In Model 4, this difference slightly drops to about 123 cubic feet of natural gas. Also, Models 3 and 4 reveal statistically significant, albeit, moderate relationships between heating degree days, a proxy for weather conditions, and natural gas consumption. These findings are all consistent with the PTEM research tradition.

Nearly all the statistical control variables included in the models are significantly related to natural gas consumption, and mostly in the direction one would reasonably expect. For instance, home ownership (own=1), number of household members, and sleeping hours temperature during winter are all positively related to natural gas consumption (Table 9). Also, the data suggest that households that use electricity and other fuels for water and space heating consume significantly less natural gas.

In Table 10, we further look at the relationship between residential location and race on the one hand and natural gas consumption on the other. We conduct these supplementary analyses to control for the effects of a wider set of indictors of investment in energy efficiency. This additional set of indicators is only available for the 1993 sample. In doing this, our objective is to further assess the effects of energy efficiency improvement on residential natural gas consumption. In these supplementary models, we find no significant differences in natural gas consumption by residential location. However, for other variables, the results reported in Table 10 do reflect those in Table 9. Consistent with the fixed effects models reported in Table 9, those reported in Table 10 reaffirm the finding that natural gas consumption varies by race. African-Americans consume significantly more natural gas per annum than whites. This relationship strengthens quite substantially between Model 1 and 3. For this sample, the other minority race groups do not appear to differ from whites in energy consumption once the effects of housing characteristics, investment in energy efficiency, weather conditions, and the statistical controls are taken into account (Table 10).

The results reported in Table 10 continue to show quite strong relationships between housing characteristics and natural gas consumption (Models 2 and 3). Several indicators of energy efficiency are also related to natural gas consumption. Respondents who reported that their water heaters were insulated consumed about 53 cubic feet less natural gas than those without insulated water heaters. As expected, Model 3 (Table 10) reveals a positive relationship between heating degree days and natural gas consumption. Finally, consistent with the results reported in Table 9, nearly all the control variables in this set of models (Table 10) remain significantly related to natural gas consumption.

CONCLUSIONS

Drawing on two analytic traditions, the physical-technical-economic models (PTEM) and the lifestyle and social-behavioral (LSB) approach, we considered whether observed residential location and race differences in natural gas consumption are functions of variations in housing characteristics, investment in energy efficiency, and weather conditions. The PTEM tradition assumes that the physical characteristics of buildings, efficiency improvement in energy conversion and use, and economic and environmental factors are integral to understanding and managing energy consumption in the built environment. The lifestyle and social-behavioral tradition questions this view, contending that focusing on these factors alone is inadequate in explaining energy consumption in the built environment. We started our analyses by first considering if natural gas consumption did vary by residential location and race. We did find in our initial models that natural gas consumption varies by residential location. Accounting for differences in housing characteristics and other pertinent statistical controls

TABLE 10. OLS REGRESSION MODELS OF HOUSEHOLD NATURAL GAS CONSUMPTION, 1993 SAMPLE

	Model 1		Model 2		Model 3	
	b	S.E.	b	S.E	b	S.E.
Residential Location						
Town.	30.4	29.8	25.3	26.4	3.0	25.4
Suburbs.	2.7	23.0	32.1	20.9	-7.1	19.4
Rural.	0.1	45.5	-5.3	35.6	-41.2	32.5
Race						
Black.	179.6***	33.0	189.6***	29.1	228.7***	26.7
Native American.	-181.9*	84.0	-62.6	66.1	-47.3	67.1
Asian American.	-249.8***	48.8	-154.3**	46.9	-42.7	40.5
Other.	-62.7	194.8	-129.8	114.6	-174.9	110.1
Hispanic.	-98.8	70.1	-32.3	67.9	30.1	46.7
Housing Characteristics						
Age of home.			42.8***	3.1	30.2***	3.0
Bedrooms.			91.1***	16.0	99.8***	14.6
Square footage.			0.2***	0.0	0.1***	0.0
Detached single-family.			-105.8*	41.4	90.8	52.9
Attached single-family.			-139.9**	40.9	20.2	50.1
Adequacy of home insulation						
Poorly insulated.					52.2	100.7
Adequately insulated.					-31.4	100.5
Well insulated.					-43.1	101.4
Thermostat					0.7	25.0
Outside wall insulated?						
Yes.					-36.4	25.7
DK/NA.					-36.9	30.0
Hot water heater insulated?						
Yes.					-53.4*	22.9
DK/NA.					89.1*	43.5

Hot water pipes insulated?						
Yes.					14.9	21.1
DK/NA.					43.7	31.2
Heating equipment maintained.					23.5	15.9
Type of glass sliding door used						
2-pane					34.2	28.9
2- or 3-pane w/low-e					-31.2	74.7
Not applicable					84.3**	24.7
Type of glass in most windows						
2-pane					-20.2	19.5
2- or 3-pane w/low-e					-33.5	48.5
Heating degree days.					0.1***	0.0
Cooking Fuel[a]						
Electricity.	-7.8	20.3	-25.2	18.2	-36.2*	16.9
Other fuels.	-170.8**	64.4	-643.6***	62.2	-645.1***	68.1
Space Heating Fuel[a]						
Electricity.	-540.8***	27.0	-423.4***	28.2	-280.7***	33.7
Other fuels.	-667.1***	32.5	-774.6***	33.7	-787.5***	36.9
Water Heating Fuel[a]						
Electricity.	-196.2***	28.9	-172.7***	27.1	-191.9***	27.1
Other fuels.	-168.6***	44.4	-94.4*	47.0	-75.7	48.4
Own Home.	247.1***	20.7	92.9**	29.3	97.7***	27.7
Income (1993 real dollars).	0.0***	0.0	0.0	0.0	0.0*	0.0
Number in household.	58.4***	8.6	21.6**	7.9	21.9**	7.5
Member at home always.	68.8**	20.3	28.1	18.2	38.9*	17.1
Winter Sleeping hours temp.	6.3**	2.2	9.7***	2.0	9.7***	1.8
Received heating aid						
Yes.	81.9	58.7	37.5	55.7	5.2	54.7
Not applicable.	-75.7*	31.2	-42.1	28.2	-24.6	26.0
Intercept.	169.9		-754.7		-1221.4	
N.	3446.0		3330.0		3327.0	
R-Squared.	0.3		0.4		0.5	

NOTE: *<.05; **<.01; and ***<.001; [a]The reference category is "natural gas".

did not alter this relationship. Consistent with the PTEM tradition, however, this initial difference disappears completely once the influences of investment in energy efficiency and weather conditions are held constant. Regarding our first research question, therefore, these data suggest that natural gas consumption will differ by residential location only if the effects of investment in energy efficiency and weather conditions are not taken into account. In effect and in response to the second question, our data indicate that the observed differences in natural gas consumption by residential location are functions of differences in energy efficiency investment and weather conditions. However, additional investigation of how residential location is related to the full mix of fuels used in American homes and elsewhere in the world is needed to better assess the strength of the PTEM approach.

As we posed in our third research question, we also wanted to investigate the pattern of relationship between race and natural gas consumption. The data analyzed and reported in this paper consistently show African-Americans consuming substantially more natural gas than whites. The data also show differences between whites and other groups in natural gas consumption. To what extent are these differences functions of variations in housing characteristics, investment in energy efficiency, and weather conditions? The data analyzed in this study suggest that these factors do not account for African-Americans' higher natural gas consumption. Sometimes, controlling for the effects of these variables only widened the gap between African-Americans and whites in natural gas consumption. This finding contradicts our expectation that indicators associated with the PTEM research tradition would help account for race differences in natural gas consumption. It also contradicts previous findings suggesting that minority groups have more limited access to consumption resources and other social goods (Caplovitz 1963; Duncan et al. 1972; Edwards and Ladd 2000). We note, however, that this finding provides support for the LSB tradition, which questions the adequacy of the PTEM approach in explaining energy consumption in the built environment.

Why do African-Americans use more energy (natural gas) than other groups? We believe answering this question will require additional work, especially work that will involve field-observation of energy use behaviors and patterns of a representative sample of African-Americans and other groups. Such an endeavor should include technical audits to establish the 'true' energy efficiency of respondents' homes.

As for the other minority groups (that is, minus African-Americans), however, we did find modest support for the hypothesis that race differences in natural gas consumption may be explained, in part, by differences in some indicators associated with the PTEM research tradition. We did find that controlling for the effects of investment in energy efficiency and weather conditions moderated the natural gas consumption differences between some racial minority groups and whites. For race, therefore, we find mixed support for our theoretical expectations and the PTEM research tradition.

We now comment on how some indicators associated with the PTEM research tradition (housing characteristics, investment in energy efficiency, and weather conditions) are related to natural gas consumption. Our models revealed significant relationships between housing characteristics and natural gas consumption. Consistent with past studies, we find, for instance, that home age and size are positively related to natural gas consumption. The analysis also revealed a modest relationship between investment in energy efficiency and natural gas consumption. We find, for example, that living in a well-insulated home and having an insulated water heating system resulted in lower natural gas consumption. Finally, we found consistently positive relationships between heating degree days (that is, weather conditions) and natural gas consumption in all our models. For policy, these findings suggest that one way to address energy consumption in the built environment will be to pay some attention to housing characteristics and energy efficiency improvement.

Most of the statistical control variables included in our models are significantly related to natural gas consumption. While the effects of these variables were not of primary concern to us in this research, we do comment on the observed relationship between home ownership and natural gas consumption. This is because home ownership is such a critical variable when it comes to the adoption of energy conservation measures. After controlling for the effects of home size, home age, type of home, and other critical variables, we found a positive relationship between home ownership (own=1) and natural gas consumption. This runs contrary to conventional expectations that home owners can probably conserve more energy than renters, given that it is within their control to invest in energy conservation measures, unlike renters. A possible explanation would be that the advantage home owners have in the ability to invest in energy conservation measures has been doused by the fact that our models account for the influence of investment in energy efficiency. However, even before we statistically controlled for the effects of investment in energy efficiency, home owners consumed substantially more natural gas than non-home owners. So, what accounts for home owners' higher natural gas consumption? Perhaps since home owners are more likely to be socioeconomically better off than renters, unmeasured class-related factors may be contributing to this difference. This relationship needs further investigation.

Looking to the future, we anticipate that the economic impacts of energy resource scarcity may chronically challenge society in ways that differ from the past. Historically, the challenges of energy scarcity have generally been episodic and short-lived. Better understanding of factors related to energy consumption will be necessary to mitigate the social consequence of future sustained energy price increases for vulnerable demographic subpopulations. This type of work is also necessary to develop policies aimed at curbing energy consumption overall.

In this study, we have shown the extent to which variations in housing characteristics, energy efficiency, and weather conditions influence residential location (rural-urban) and race differences in natural gas consumption. Yet in so doing, we have also uncovered the need to more closely examine the nature of energy use among different subgroups in the population. There remains a need to investigate why energy consumption still varies substantially by race, even after the effects of housing characteristics, investment in energy efficiency, weather conditions, and other critical covariates of energy consumption have been accounted for.

AUTHOR BIOGRAPHIES

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APPENDIX A. VARIABLES USED IN THE STUDY AND THEIR MISSING VALUES IMPUTATION STATUS

Indicators	1993	1997	2001	2005
Annual Natural Gas Consumption.	X	X	X	X
Residential Location.	Z (121)	Z (8)	Z (7)	Z (7)
Race.	Z (75)	X	Z (15)	Z (179)
Age of home.	Z (392)	Z (408)	Z (483)	Z (452)
Bedrooms.	Z (9)	X	Z (1)	X
Square footage.	X	X	X	X
Home Type.	X	X	X	X
Adequacy of insulation.	Z (223)	Z (50)	X	Z (58)
Thermostat?.	X	Z (2)	X	Z (61)
Outside wall insulated?.	Z (33)	-	-	-
Water heater insulated?.	Z (39)	-	-	-
Water pipes insulated?.	Z (44)	-	-	-
Heating equipment maintained?.	Z (440)	-	-	-
Type of glass sliding door.	Z (124)	-	-	-
Type of glass in windows.	Z (193)	-	-	-
Heating degree days.	X	X	X	X
Cooking fuel.	Z (13)	Z (2)	Z (1)	Z (41)
Space heating fuel.	X	Z (49)	X	Z (61)
Water heating fuel.	Z (125)	Z (126)	Z (88)	Z (209)
Home ownership.	X	X	Z (1)	X
Income.	Z (818)	Z (1031)	Z (487)	Z (576)
Number in household.	X	Z (12)	Z (14)	Z (14)
Member at home always?.	Z (54)	Z (10)	Z (8)	Z (66)
Winter sleeping hours temp.	X	X	X	Z (58)
Receipt of heating aid.	Z (199)	Z (103)	X	-

NOTE: X=No imputation; Z=Some values imputed (number of imputed values shown in parenthesis).