

## Assessing Household Energy Consumption in Adelaide and Melbourne

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**Abstract:** This paper builds on existing literature on household energy consumption and test effects of a range of factors associated with household energy use. It aims to bring out how household energy consumption varies between and Adelaide and Melbourne and identify determinants of household energy consumption. It is conceptualised that household energy consumption is determined by macro and micro environment variables, as well as household attributes and housing stock characteristics. Residential sector in urban areas is the third largest sector of final energy use in Australia and it accounts for about 12% of the country's total final energy consumption. Data were collected from a survey of 200 sample households and modelled according to a conceptual framework that takes into account household, house stock, and build environment factors. The findings contribute to understanding of the factors that shape residential energy consumption, and have policy implications in targeting household energy savings.

**Keywords:** Energy consumption; Housing characteristics; Household characteristics; Neighbourhood characteristics

### Introduction

This paper reports on household energy consumption pattern in two capital cities in Australia namely Adelaide and Melbourne. The focus is on evaluating household energy consumption with respect to housing type, location, and socioeconomic characteristics of households and expenditure on energy. It takes into account physical parameters of housing such as building style, building material, age of housing, insulation of walls and ceiling. Total net use of energy in Australia in 2009-10 was 19,296 petajoules (PJ) of which net energy used by households account for 1,015 petajoules which includes all sources of energy including fuel used for transport, renewable energy, coal, gas etc. Electricity accounts for 21.3% of gross household energy use (ABS, 2011a). This, of course, include only the operational energy not including embodied energy used in manufacturing building materials that go into building the housing. Energy consumption by housing in Australia has been estimated to be 413PJ, which is approximately 12% of total energy use (Pullen, 2010).

Household income and housing tenure influence energy consumption rates and affect the propensity to adopt energy saving measures. On average 23.7% households in Australia have less than \$600 gross weekly income where the percentage is slightly higher in Adelaide metropolitan area (26.1%) and in Melbourne Metropolitan area it is 21.3% (ABS, 2012). Low-income households have relatively less capacity to pay for energy-saving products, like solar PV systems, solar hot water or insulation, which can have significant upfront costs. Low-income households have less energy-consuming appliances in general, and fewer energy efficient appliances, and less energy efficient homes. In low income households insulation is less common, refrigerators are less efficient, and there is a greater reliance on energy intensive electric heating (ABS, 2011c).

ETSA, which owns electricity network infrastructure and supplies electricity of retail distributors in South Australia delivered 3,818 GWh of electricity in 2009 in the state, of which 33.3% was supplied to residential properties (ETSA 2009). As part of National Energy Savings Initiative the government has provided subsidies to households to improve energy efficiency and install solar photovoltaic (PV) systems.

## Household energy consumption

Understanding the dynamics of energy use is an necessary for understanding how to reduce domestic energy consumption. Several studies have measured household energy consumption. Howard et al. (2012) developed a model to estimate the building sector energy end-use intensity for space heating, domestic hot water, electricity for space cooling and electricity for non-space cooling applications in New York City. They found that end use of energy consumption is primarily dependent on building function and not on construction type or the age of the building. This is a startling finding given that government initiatives in Australia to promote energy efficiency in housing sector focused on ceiling insulation, adoption of solar energy systems, and energy efficient housing construction.

Since Australia and the United States did not ratify Kyoto Protocol, Australia's commitments do not involve a numerical CO<sub>2</sub> reduction. The government, however, has carried out a large amount of analysis and strategic forward planning to curb energy consumption and greenhouse gas (GHG) emissions. The Garnett Climate Change Review commissioned in 2007 studied impacts of climate change on the Australian economy. The final report includes proposals to reduce carbon emissions in a phased manner. Several schemes have been introduced over the past five years including \$2.5 billion Home Insulation Program under the Energy Efficient Homes Package as part of the Nation Building Economic Stimulus Plan (2009) and subsidy to households, about 1.1 million households were insulated until it was abolished in February 2012, solar hot water rebate, solar installation rebate, and solar credit.

The average floor area of all new residential dwellings in Australia increased from 149.7m<sup>2</sup> in 1985 to 218.9m<sup>2</sup> in 2009, an increase of 46.2%. At the same time average floor area of new houses increased from 162.4m<sup>2</sup> to 248.0m<sup>2</sup> (52.7%) (ABS, 2010). The typical house in Australia has evolved from having three bedrooms, one bathroom and separate living area into a more open plan including a fourth bedroom and ensuite facilities (ABS, 2005). This is not just an isolated phenomenon confined to Australia. The size of average new house in US expanded from about 93m<sup>2</sup> in 1950 to 218m<sup>2</sup> in 2004, which Rees (2009) described it as unprecedented levels of unsustainability. Given the popular predominance of large house phenomenon in Australia, scholarly research on the topic is rare (Dowling and Power, 2012). It does not necessarily imply researchers were silent on this issue. While presenting his views on ecological footprints of ever-increasing consumption of resources and its implications for the building sector Rees (2009) have highlighted and condemned the widespread preference for supersized houses in developed countries, in particular Australia and the US.

Between 1911 and 2006, average household size in Australia fell from 4.6 to 2.6 people. This means floor area per capita increased faster than increase in average floor area. Given that energy costs in Australia, in spite of electricity price hikes over the past three years, is still among the lowest in developed countries and it may not be at the top of household budget could be an incomplete answer for low levels of adoption of household energy saving measures. It could be inferred by the frequency with which policy debates on energy prices and energy efficiency in media and public discussion appear. On the contrary, mortgage interest rates on home loans and house prices constitute a large chunk of household budget and often dominate public discussion.

Experts express concerns that household energy consumption has only a limited set of substitutes. They fear that to the extent designers and engineers are overly optimistic about reducing the energy footprint of housing, reduction in energy footprint would lead to increase in embodied energy that goes into the production of building materials often causing cost of house building expensive and unaffordable to low income households. A major goal of planning and building technology is to increase our understanding of the ways in which energy footprints can be minimised without reducing comfort levels and maintaining cost of buildings within the reach of households.

Environmental advocacy, information on environmental benefits, and incentives do not guarantee behavioural changes. There are plenty of experiments and empirical evidence of energy savings in housing sector in Australia. They range from retrofitting existing houses with suitable ceiling insulation supported by government subsidy, government grants to households for solar photovoltaic panel installation, feedback tariffs, solar hot water systems to mandatory building codes such as minimum energy rating for new houses and compulsory rain water tanks. The general issue of behavioural change is revoked often in energy studies and housing preferences. Janda (2011) has emphasised behaviour of people and its potential in reducing energy consumption in housing (Maréchal and Holzemer, 2011). This is not to deny the role of better design in reducing energy consumption. Energy efficiency gains in the US over the last four decades have been outpaced by increases in size and features and increasing use of energy consuming equipment and energy efficiency alone is insufficient to reduce energy consumption by households (Harris et al., 2006). Several studies estimated carbon dioxide emissions of housing at regional scale looking at developments of various densities and found higher population concentrations reduce overall energy use (see Pitt, 2012). Energy performance contracting (EPC) is a widely used by energy companies to estimate potential energy savings of large consumers and advice consumers. Kellett and Pullen (2012) highlight potentials of EPC in saving energy consumption in residential sector in a “less matured” energy market such as Adelaide. A baseline study of energy consumption in South Australia found typical houses in Adelaide consume about 40GJ per annum (Oliphant, 2003) which is approximately 280MJ/m<sup>2</sup> of floor area for the average-sized single story detached house.

Ewing and Paul (2008) used pooled data from several databases and examined the relationship between housing size, housing type and energy consumption in the context of urban sprawl. They found that average households in single-family homes use 54% more energy for heating 26% more energy for cooling than comparable households in multi-family dwellings. They found that compact counties in the US require about 20% less energy than sprawling counties. Bigger houses need more energy not only because of the floor area but also they generally have swimming pools and more appliances than smaller houses. Larger floor area of housing and the number of appliances requiring energy are two distinct but related issues that go hand in hand and generally reflected in household income. Earlier studies, for example, Nesbakken (1999) treat housing and energy technology choices such as number of appliances as jointly determined endogenous variables. However the distinctions lie buried in average statistics on household energy consumption. For example, (Spanos et al., 2007) used Carbon Abatement (CARB) methodology and estimated CO<sub>2</sub> reduction in UK housing from different technologies with different environmental implications and quantified the cost of reducing CO<sub>2</sub>.

Natarajan and Levermore (2007) analysed UK housing stock and projected energy demand for six categories of energy used in housing under different climate change scenarios adopted by IPCC 2007. Although building occupiers are not taken into account, hence differences due to demographic and socioeconomic factors are excluded it is adequately disaggregated to foresee energy demands of a range of housing and construction types.

Over the years the average household energy bill increased from \$437 in 1996 to \$654 in 2001 and up to \$1000 in 2005 (ABS, 2011b, 2011d; DHS, 2002). The proportion of households using solar energy in Australia increased from 5% in 2002 to 8% 2008 (ABS, 2011b). Since 2009 federal and state governments actively promoted solar hot water systems and solar photovoltaic systems through subsidies to households and solar feed in tariff incentives. In 2011, about 5% households in Melbourne had solar panel systems and 4% solar hot water systems (ABS, 2011d). The uptake of solar hot water systems is more widely dispersed and possibly reflecting new building activity and the possibility to use solar hot water systems in new homes.

Uptake of solar hot water and solar panels at home is marginally higher in Adelaide than Melbourne. In Adelaide 4% and 4.6% households have solar hot water and solar electricity systems respectively, whereas in Melbourne 2.3% household had hot water systems and 4.0% solar electricity systems (ABS, 2011b). Negligible percentage of households has both the systems; 0.3% in Melbourne and 1.2% in Adelaide (ABS, 2011b). This probably reflects the geographical advantage of Adelaide located in climate zone 6 with relatively hotter summer and more number of sunny days is better positioned for solar energy than Melbourne located in climate zone 5. Moreover, availability of government grants and subsidies for solar systems and feed in tariffs are crucial for their uptake in residential sector.

Research linking energy consumption and transport is well established compared to studies on residential energy consumption that help trace parameters influence energy consumption. An expanding number of studies use residential energy consumption to estimate carbon footprints at city or regional level. Glaeser and Kahn (2010) analysed carbon dioxide emissions in 66 cities in the US and found that variation in climate or availability of mass transport does not adequately explain substantial differences in energy use across cities. They observe that fundamental characteristics of development have a profound effect on energy use in cities. Spatial distribution of population and population densities are important determinant of carbon emissions and older and denser cities have lower carbon dioxide emissions. Their study is based on data already available but does not include household characteristics and housing types. Dodman (2009) present inventories of greenhouse gas emissions for a number of cities across the world and rule out influence of climate or city size as the cause of differences in carbon footprint. Dodman highlight large variations within the US. District of Columbia's GHG foot print per capita is much higher than that of New York. Though not proved through analysis he conclude that smaller than average dwelling unit size and well developed mass transit in New York reduce the demand for automobile use.

Larson, Liu and Yezer (2012) developed Urban Energy Footprint Model (URFM), linking residential energy consumption to energy price, employment distribution, income groups, and commuting congestion in five moderate size cities in the US. The model allows estimating the implications of a change in land use zoning or transportation policy through its effects on housing markets to the resulting changes in energy use for residential and commuting purposes.

## Methods

Household energy consumption in Adelaide and Melbourne was analysed. Climate conditions and temperature has marked effect on energy demand. Melbourne is located in climate zone 6 with mild temperate climate conditions and Adelaide in climate zone 5 with warm temperate climate conditions. Geographical location and thus climate conditions result in different heating and cooling requirements: homes in Melbourne require more heating than cooling whereas heating/cooling requirements of Adelaide is more balanced. Heating degree days (HDD) and cooling degree days (CDD) measures the deviation of mean temperature from a base temperature which is a temperature where neither cooling nor heating is used. Howden and Crimp (2001) estimated base temperature 16.8°C for Adelaide and 16.9°C for Melbourne where neither heating and nor cooling is required. Sailor (2001) used heating and cooling degree days to explain variance in energy demand in major Australian cities.

Household survey ( $n = 200$ ) was conducted in ten suburbs in Adelaide and Melbourne to measure household energy use including electricity, natural gas, coal and fire wood consumption. Five suburbs each in Adelaide and Melbourne were chosen based on socioeconomic characteristics and location within the metropolitan area to systematically cover households from all income ranges and dwelling units built in different periods. The ten sample suburbs from two cities represent low income to middle and high income groups in each city. Twenty households from each suburb were randomly selected for the household survey. Table 1 provides housing and household income characteristics of sample suburbs.

**Table 1. Household income, population and dwelling characteristics of sample suburbs in Adelaide and Melbourne**

No.	City	Suburb	Median household income per week, 2006 (\$)	Population, 2006	Total dwelling units, 2006
1	Melbourne	Berwick	\$1,222	36419	12125
2	Melbourne	Camberwell	\$1,668	19637	6840
3	Melbourne	Coburg	\$1,019	23721	8653
4	Melbourne	Heidelberg West	\$577	5096	1954
5	Melbourne	Melton South	\$837	8798	3150
6	Adelaide	Beaumont	\$1,597	2444	849
7	Adelaide	Davoren Park	\$561	6780	2574
8	Adelaide	Flagstaff Hill	\$1,367	9418	3194
9	Adelaide	Prospect	\$1,060	12381	4812
10	Adelaide	Woodville West	\$751	2916	1157

Source: *Census of Population and Housing 2006*, Australian Bureau of Statistics, Canberra.

The sample suburbs are geographically distributed within the respective metropolitan areas so as to cover housing units built over different periods and reflect variations in housing size, housing style, housing type and age of housing. Prospect in Adelaide and Camberwell in Melbourne are inner city matured suburbs built around 1920s. Deveron Park, Flagstaff Hill, Heidelberg West were built over the last twenty five years or so. Berwick and Melton South in Melbourne are relatively new suburbs developed in the past ten years. Thus the sample suburbs represent all housing ages and housing styles in different parts of the two metropolitan cities.

### **Data collection**

Data on dwelling type, dwelling size in terms of number of bedrooms, single or double storey, age of housing, wall and roof material were collected through the survey. Types of energy used for lighting, cooking, space heating, space cooling, and hot water systems were collected. Presence of solar photovoltaic panels, solar hot water systems, window double glazing and rainwater tanks were also recorded. In addition, households were asked if they have purchased or installed any energy saving appliances including ceiling fans, installed ceiling insulation, sky lights, smart power meter, double glazed windows, solar hot water systems, solar panels and energy efficient light bulbs. In addition intention to install specific energy saving measures in the near future were collected. Besides information on household characteristics namely housing tenure, age of head of household, household type, employment and retirement status, home ownership, and household income and years of stay in present houses were collected. Although 100% households had mains electricity, availability and uptake of LPG (natural gas) varied within and across suburbs in both cities.

The household survey was carried in June 2012 just a month prior to the introduction of carbon tax in Australia and households were asked if they were aware of the impending federal carbon tax. The main aim was to evaluate household energy consumption for maintaining and operating the homes. Even though the survey collected distance to work and education and services, vehicle ownership, car engine size, yearly kilometre run, car sharing, expenditure on fuel, travel distances to work, education, shopping and other purposes they are not presented in this paper. Thus energy consumption of transport is not included in this paper.

Expenditure on electricity and gas was collected for the latest quarterly billing cycle. In Adelaide and Melbourne households receive energy bills in three months cycle. The charges include fixed supply

charges and cost of energy consumption measured in kWh electricity and mega joules gas. Since the deregulation energy distribution in the two states several distribution companies have entered the energy distribution market and provide energy to households. There are over twenty electricity and gas suppliers in the two cities charging slightly varying units rates and different slab pricing systems. Electricity and gas prices provided by the government regulators were used to calculate kWh electricity and mega joules gas consumed by households into an equivalent kWh. Conversion factors were used to aggregate electricity, natural gas and other forms of energy into a single energy consumption index.

## Results

Household characteristics include economic and behavioural variables that are specific to households irrespective of where they live. Energy used for maintaining and operating the homes excluding energy used by private automobiles although vehicle ownership is taken into account as an explanatory variable of energy use. Similarly embodied energy used in the production of materials used in construction of housing is not included in the analysis. Household energy consumption data was used to model household characteristics and housing characteristics that explain energy use across sample suburbs. The basic formulation of the model is:

$$\text{Energy use} = a * \text{Household characteristics} + b * \text{Housing characteristics} + \varepsilon$$

Housing is a durable commodity and our sample includes housing built over a long period of time. Housing characteristics are qualitative and quantitative parameters that do not easily change in the short run. Wall material and type of construction, for example, cannot be easily changed without considerable expenses to household. Thus our sample includes a typical mix of housing stock in Adelaide and Melbourne. Most predominant outside wall material in Adelaide and Melbourne are brick veneer and double brick which is increasingly adopted throughout Australia. As shown in table 1, outside wall material of 40% houses in Adelaide is brick veneer whereas it is 58 % in Melbourne. On the other hand outside wall material of about 46% houses in Adelaide is double brick and in Melbourne it is a mere 14.9%. Slightly higher percentage of houses (39.5%) in Adelaide has wall insulation whereas it is just 31.6% in Melbourne.

About nine out of ten dwellings in Melbourne have mains gas connection whereas in Adelaide only three out of four dwelling units have mains gas connection. About 10% more households in Melbourne use mains gas for water heating than in Adelaide. Moreover, winter in Melbourne is slightly colder than that of in Adelaide which might explain the differences in the type of building material and amount of energy used by households in these two cities. Electricity is most common source of room heating in Adelaide whereas 73% households in Melbourne use gas for room heating. Significantly higher percentage of dwelling units (9.3%) in Adelaide has solar photovoltaic panels. In comparison only 5.5% of dwelling units in Melbourne has solar panels. Thus differences in building material and energy mix might be the reason for poor explanatory power of the regression model presented earlier. Moreover, the two cities are different in population size, size of the urban area, and climatic conditions that lead to differences in building material, operating energy requirements, length and intensity of heating and cooling requirements. Controlling for these differences in climatic conditions, city size and population size is necessary to identify factors that impact on household energy consumption. Table 2 and 3 depict the regression models for Adelaide and Melbourne.

**Table 2. Regression results for household energy consumption for Adelaide**

Dependent variable	Coefficient	t-Statistic	p-value
Constant	2921.556		0.117
Dwelling type - detached house	2128.018**	0.1982891	0.050

Size of dwelling (number of bedrooms)	866.359*	0.1872371	0.074
Wall material - double brick	3812.318***	0.3981791	0.002
Wall material - brick veneer	3278.578***	0.4309334	0.001
Length of time staying in the same house (years)	-151.521***	-0.379415	0.000
Energy saving device - open fireplace	3975.249***	0.3216099	0.001
Electricity use - room cooling	2052.644**	0.2040781	0.020
Self-assessed energy affordability	-1339.178***	-0.3553127	0.000
Energy use change - outside awnings / blinds	1889.372*	0.1614529	0.080
Future change to energy use - turn off appliances	1857.204	0.140754	0.112
Household type - group household	3981.785**	0.2207032	0.035
Gross household income per year	103.653	0.01417578	0.719
Number of bicycles in household	573.198**	0.2426274	0.020
Vehicles in household - company cars/vans	1400.416	0.1500975	0.135
Weekly fuel consumption (litre)	-75.661***	-0.447446	0.002
Driving distance in last year (km)	-0.070	-0.130476	0.144
Amount spent on fuel per week (\$)	47.264**	0.3187269	0.029
R <sup>2</sup>	0.8347		
Adjusted R <sup>2</sup>	0.7441		
F-statistic	9.21		
Prob (F-statistic)	0.000		
***p<0.01, **p<0.05, *p<0.1			

**Table 3. Regression results for household energy consumption for Melbourne**

Dependent variable	Coefficient	t-Statistic	p-value
Constant	-1783.650		0.644
Size of dwelling (number of bedrooms)	2416.282***	0.2950272	0.007
Age of house	-401.937	-0.1095232	0.308
Wall material - brick veneer	-3267.343**	0.2671748	0.017
Electricity use - cooking	3382.922*	0.286932	0.071
Gas use - cooking	2426.415	0.200595	0.172
Gas use - room heating	2518.298*	0.1786503	0.088
Self-assessment of energy affordability	-1390.098**	-0.2711621	0.013
Energy use change - solar panels on roof	-4362.417***	-0.3029105	0.005
Current employment status - part-time	-2131.005	-0.157769	0.137
Gross household income per year	2022.365***	0.5300956	0.000
Vehicles in household - company cars/vans	-721.746*	-0.2045738	0.088
Main fuel type of cars/vans - Diesel	2233.739	0.1257418	0.232
Weekly fuel consumption (litre)	-19.877	-0.0781582	0.508
R <sup>2</sup>	0.7275		
Adjusted R <sup>2</sup>	0.6234		
F-statistic	6.98		
Prob (F-statistic)	0.0000		
***p<0.01, **p<0.05, *p<0.1			

In case of Adelaide the model explains 83.47% of variance in energy consumption and in case of Melbourne it explains 72.75% of variance. In other words, regression models of observations drawn

from the same metropolitan area have stronger explanatory power mainly because exogenous variables such as climate conditions and the effect of city size are removed from the analysis. There are important differences as well. In case of Melbourne, the size of dwelling unit, wall material brick veneer, solar panel at home and gross household income are statistically significant at 1% level. Coefficients for wall material brick veneer and solar panel are negative and coefficient for solar panel is substantial at -4362.417. Type of energy used for cooking and space heating are statistically not significant. So as household vehicle ownership and weekly fuel consumption for private automobiles that does not explain household energy consumption. Wall material double brick with negative coefficient sign is statistically significant at 1.7% level.

In case Adelaide a large number of variables account for household energy consumption. Two prominent types of wall material namely brick veneer and double brick, open fire place, self-assessed energy affordability and weekly fuel consumption of private automobiles are statistically significant at 1% level. Unlike Melbourne, size of dwelling and gross household income in Adelaide is statistically insignificant. Detached dwelling, use of electricity for room cooling, group household, type and amount spent on fuel per week are statistically significant at 5% level. Open fire place for room heating and electricity operated room cooling account for higher energy consumption.

### **Discussion and conclusion**

Combined models and city specific models of energy consumption and expenditure on energy support the hypothesis that housing characteristics and household characteristics play dominant roles in energy consumption. Dwelling unit size measured as number of bedrooms is a consistent variable that influence energy consumption and the regression results support policymakers' contention that size matters. Dwelling unit size controlled for location has a strong positive correlation to household income and amenities. The results indicate that size of dwelling and household size are important determinants of energy consumption and have the expected positive sign. Preferences towards adoption of energy efficient appliances effect on reducing energy consumption and thus reduce energy cost. However adoption of energy efficient appliances is not as strong a variable like size of dwelling. Promotion of energy efficient housing and solar energy units at home in Australia is fairly recent and the uptake of such measures is inconclusive. Among the range of energy efficiency related variables, different sets of variables in each city explain energy consumption. Investigation into why a particular variable is effective in one city whereas it does not have the same influence in the other is outside the scope of this paper. Nevertheless the analysis points to sensitivity of energy efficiency variables in two cities that have important policy implications.

Comparisons of household energy consumption are important because they bring out existing differences within and between cities. They are also important for the questions they raise about housing and planning policies. Currently there is a tendency to evaluate energy efficiency in terms of energy rating of new housing without necessarily addressing the issue of size of housing. The analysis has shown that even though adoption of energy efficient appliances and solar panels have some influence in reducing energy consumption they have much smaller impact than the size of dwelling.

While the model has been calibrated for two capital cities in Australia, the methods are clearly applicable to other cities around Australia and elsewhere. The model also has limitations. The analysis did not explicitly investigate the role of city size on household energy consumption and energy cost. Climate variations are not explicitly built into the model to account for location. Second energy consumption data collected through household survey covers only the latest three months which is in fresh memory and thus more accurate. Ideally a full twelve month data on energy consumption data reveal the net differences between cities.

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