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How do we use energy in our homes — To suit buildings or behaviour?

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Introduction

In a recent paper, Moriarty (2002) reviewed the use of energy in different spatial realms — capital cities, other urban areas and rural areas. Within capital cities, Moriarty also explored the differences between metropolitan inner and outer areas. His analysis drew on data associated with a number of variables including *per capita* expenditure on domestic fuel and power; the nature of the dwelling stock and road provision in inner and outer urban areas; and travel characteristics. Within this spatial framework, Moriarty explored the potential of these variables to enhance sustainability. He concluded there is little difference between these spatial realms in terms of overall sustainability, but that conditions which encourage the shift of travel to electric public transport and non-motorised modes have the most potential to advance greater sustainability.

There have been very few such attempts to examine energy use in different kinds of urban localities. It is a complex issue, complicated by the number of influences involved. For example, apart from the *operational* energy used from day to day in the city, there is a store of sunk energy or *embodied* energy in the built form and capital equipment of cities (i.e. the buildings, road, pipes, wires and other infrastructure including the fleet of vehicles of various kinds used for travel). Further, the operational and embodied energy demands are only a proportion of the *primary* energy needed to generate, refine or manufacture energy in its various forms and distribute it. In addition, the energy demands of the city are drawn from a wide hinterland expanding the 'ecological footprint' of the city beyond the built up area (Yencken and Wilkinson 2000). All these dimensions need to be considered if we are concerned with the generation of greenhouse gases.

A recent pilot project in Adelaide was carried out by the Urban Frontiers Program and the Centre for Resource and Environmental Studies at the Australian National University in conjunction with Planning SA (Troy *et al*., 2002). It measured the water and energy used in different built forms in six localities. In doing so it sought:

- to establish more precisely what were the characteristics of energy and water consumption in areas of different character, location and built at different time periods:
- to construct a comprehensive inventory of operational energy use, embodied energy use and the consequent demand for primary energy in those areas;
- to shape an understanding of the determinants of energy use;
- to identify the relative importance of different kinds of demand for energy; and
- to shape policy measures that are most appropriate for encouraging greater sustainability of urban areas.

The exercise was comprehensive and successful in obtaining the energy and water profiles of residential development. This paper is a spin-off from that exploratory study and, as such, it should be read in conjunction with Troy *et al.* (2002). The pilot project identified a number of areas for more specific research, and this paper outlines one of these — what are the determinants of household demand for operational energy in the home? This excludes the operational energy used for travel.

The paper starts by examining the importance of household energy use and research into it. It reviews studies from around the world that have measured and investigated the characteristics of such consumption. It then concentrates on relevant research of this kind in Australia. It goes on to distil the main determinants of energy use by households and discusses the important phenomenon of intercorrelation between these influences.

From this theoretical context, the empirical data collected from the Adelaide pilot project is examined to shape preliminary conclusions about what causes households to use energy in the way they do. This data is presented for the six small case study areas representing different types of urban development. It is then possible to foreshadow two further research projects that can more fully illuminate the reasons for differentiated energy use by households, and how this might enrich policies to conserve the use of energy through regulatory and pricing mechanisms.

Energy Consumption Levels in Australia

Australia's energy consumption reflects both the expanding Australian population and the growth of the national economy. In 1998, 80 per cent of greenhouse gas emissions were attributable to the energy sector (ABS, 2001a). Between 1977-78 and 1997-98 Australia's energy consumed per annum increased by 61 per cent (ABS, 2001a). During the same period the amount of energy used *per capita* increased by 24 per cent from 209 Gigajoules (GJ) to 258 GJ (ABS, 2001a), although this varied across States.

Hamilton and Turton (2002) note that between 1982 and 1997 Australia's *per capita* emissions increased slightly more than the OECD average. Australia along with Canada and the USA had high *per capita* energy related emissions. Furthermore, in absolute terms, these three countries had the highest rate of *per capita* emissions of all the countries in the OECD.

The Australian Government has set a target for national greenhouse gas emissions of 108 per cent of 1990 levels by 2010 (Australian Greenhouse Office, 2002). Recent reports estimate that this will be exceeded by 3 per cent, and that voluntary industry targets have not been effective and need to be replaced with higher mandatory renewable energy targets and a moratorium on new coal-powered generators (Garnaut, 2002).

Electricity generation accounts for about one-half of Australia's energy related greenhouse gas emissions (ABS, 2001b). Total transport activity, including industrial and domestic use of motor vehicles contributes about one-quarter of these emissions (ABS, 2001b). However, household consumption (for example, electricity consumption and car usage) is responsible for around 56 per cent of total (energy-related) emissions (ABS, 2001b).

Understanding Household Energy Consumption Patterns

There are a number of factors influencing household energy use. Household consumption patterns can be influenced by a range of factors including, but not limited to, income, transport needs, climate, dwelling structure, and by personal and lifestyle factors. In essence, this is one of the problems in trying to better understand household consumption patterns — its multi-dimensional nature.

Nevertheless, it is important to try to do this for a number of reasons. Firstly, as we have already noted household consumption is responsible for around 56 per cent of Australia's total energy related emissions. This is because a household's sphere of influence extends beyond the residential sector. Ironmonger *et al*. (1995) noted that even though transport and manufacturing represent a large proportion of total energy use, both these sectors are influenced by the demand for goods and services by households.

Secondly, and following on from the first point, is that whilst national benchmarks and targets are necessary for Australia's international obligations the site of demand is actually at a local or household level. There have been a number of studies that have revealed differences in energy consumption between countries (Haas, 1997; Schipper *et al*., 1997; Greening *et al*., 2001; Al-Faris, 2002; Hamilton and Turton, 2002) and there have also been studies examining household energy use at broad spatial levels (Munksgaard *et al*., 2000; Shorrock, 2000; Vringer and Blok, 2000; Yust *et al.,* 2002). However, there seems to be a lack of attention given to the role of households as an economic unit (Ironmonger *et al*., 1995), particularly in Australia. In addition, it has been suggested that as the site of demand is the local level then change will need to occur at this level (Bennett and Newborough 2001).

Thirdly, a number of studies have revealed that there have been increases in household energy consumption and emissions over time, however, if it were not for more energy efficient appliances or energy conservation programs, then overall emissions would have been much higher than they were (Shorrock, 2000; Vringer and Blok, 2000). For example, Shorrock's (2000) study in the UK estimated that carbon dioxide emissions would decrease by 5 Megatonnes of Carbon (MT C) by 2000. This would be the result of a 13 Mt C increase in household emissions and a decrease of 18 Mt C due to improved insulation, heating and changes to electricity supply. As Munksgaard *et al.,* (2000) have suggested 'generally speaking, measures focusing on influencing household consumption habits may provide an advantageous means of curtailing CO_2 emissions' (p. 436).

Fourthly, Banks (1999) contemplated the question that, generally, energy efficient appliances do not cost any more than their less efficient competitors in Europe. The energy labelling system set up by the European Union also allows easy comparison. So why aren't consumers demanding higher efficiency standards? Banks concludes that the answer lies in consumer values. He goes on to suggest that if we are to encourage more persons to buy energy efficient products then we need to know the socio-economic, cultural and demographic factors that influence such decisions.

Finally, in an interesting study Clinch and Healy (2001) tried to incorporate the health and comfort benefits into a cost-benefit analysis of domestic energy consumption.

Their theory was that only the monetary benefits of domestic energy conservation programs are considered in cost-benefit analyses. They tried to incorporate other benefits, i.e. health and comfort, into such an analysis. However, they concluded that such an analysis is a long way off. They encountered difficulties because, among the many assumptions built into their analysis, they had to make several speculative ones concerning household behaviour due to the limited knowledge about household consumption patterns.

Together, these characteristics establish the significance of energy use in the home, emphasising its importance as an economic unit of consumption. As such, action is needed at that level to address broad policy issues such as the conservation of energy, the management of natural resources, and limitation of greenhouse gas emissions. In addition, as advanced in the Adelaide exercise we need to understand more about the energy demands, both operational and embodied of different kinds/localities of urban development and change.

Having established the importance of household energy use we turn to review international and then Australian studies about the nature of such energy use.

Research on Household Energy Consumption

There have been a number of studies examining household energy consumption. In the 1970s the Princeton Twin River experiment (Seligman *et al.,* 1978) examined the role of occupant behaviour and energy use. They found that in townhouses with identical floor plans and appliances, the variation in energy consumed for space heating in one unit was sometimes double that of the adjacent unit (Yust *et al.,* 2002). Furthermore, when all the townhouses were retrofitted with energy saving measures, which reduced consumption by 25 per cent, the variation in energy use which existed before remained almost the same.

Larivière and Lafrance (1999) contended that the average inhabitant age, the annual degree days below 18 degrees Celcius, the urban density, the share of homes heated by electricity and the standardized land wealth per inhabitant were the determining factors in explaining the electricity consumed in Quebec. They suggested that 'a one thousand dollar (CAN$1991) increase in the land wealth causes an electricity use growth of 120 kwh/inhabitant/year' (p. 61).

Halvorsen and Larsen (2001) found that the total electricity consumption of Norwegian households increased by an average of 3.1 per cent annually between 1976 and 1993. They estimate that 45 per cent of the growth in residential electricity consumption was due to the increase in the number of households and 55 per cent were due to changes in factors that influence the various households' electricity consumption.

Pachauri and Spreng (2002) examined the direct and indirect energy use in Indian households during the period 1983-84 to 1993-94. They found that direct energy use increased by 14 per cent during the period with the use of electricity growing the fastest. As far as total consumption goes they found that the average *per capita* total energy requirement of private consumption increased from 11.2 GJ to 12.1 GJ.

Further analysis revealed that changes in economic activity levels, measured by real *per capita* household expenditure, were responsible for a 55 per cent increase in total household energy requirements. Population changes led to a 29 per cent increase in total energy use. As such, rising real *per capita* expenditure in India was the largest contributor to increasing energy requirements during the period (an overall 43 per cent in real *per capita* expenditure over the study period translated into an 8 per cent increase in *per capita* total energy requirements).

Greening *et al*., (2001) analysed the development of carbon emission trends in 10 OECD countries. In the countries they studied they found that as *per capita* income increased so did emissions. They suggest that in all countries there was an increase in consumption related to the number and variety of small and personal household appliances. They conclude by stating that as incomes rise, energy consumption will continue to grow.

Munksgaard *et al.,* (2000) found in Denmark that 'overall growth in household consumption of energy as well as other commodities was found to be the main driving force behind growth in CO_2 emissions over the period 1996-1992' (p. 436).

Probably the most intensive examination of household energy consumption behaviour has been carried out in the United States by Yust, Guerin and Coopet (Guerin *et al.*, 2000; Yust *et al.*, 2002). From its exhaustive review of previous research it identified a large number of variables influencing energy consumption in the home. These mainly related to the *characteristics* of people including age, income, whether the home was owned, education, number of occupants, physical size of the dwelling, degree of daily occupancy, gender, and presence of a home handyman. But it also included occupant *attitudes* to comfort, health concerns, motivation to conserve, and folk knowledge.[1] In addition, *actions* such as insulation and draught-proofing, response to incentives and participation in an energy audit program were variables that also influenced energy consumption in the home.

In essence, these researchers developed a theoretical model to organise these various variables, called a human ecosystem model, where the person, household or family (the human organism) interacted with the natural, social and designed environments. Understandably, the review and analysis is then dominated by human behaviour. The empirical analysis is also confined to owner-occupied, single family detached residences, although it does introduce more data on physical characteristics such as the age of the dwelling and the size of heated and unheated areas.

In contrast is the work of Jones, Lannon and Williams in Wales (Jones *et al.*, 2000 and 2001). Their energy and environmental prediction (EEP) model contains a domestic sub-model which provides an energy rating for a dwelling. The five critical characteristics used to determine this energy rating are heated ground floor area (m^2); façade (m^2); window to wall ratio; exposed end area (m^2); and age of the dwelling. These features are considered to have the greatest effect on domestic energy use. When integrated with sub-models concerning commercial and industrial processes, and travel, the total EEP model predicts and accounts for energy use within an area. This allows plans to be made to reduce carbon dioxide and other emissions. In this model, however, there is no consideration of the socio-economic determinants of energy use.

The conclusions from this review are of the multi-layered and complex nature concerning the factors influencing the use of energy by households. Researchers have tended *either* to emphasise the nature of the household as the main determinant, *or* conversely the character of the dwelling it lives in. Part of the reason for this is the lack of detailed information at the individual household level about energy consumption together with the physical characteristics of the dwelling, and the kind of household living in it. The other problem is the intercorrelation among physical and human variables, which is discussed below.

Research on Household Energy Consumption in Australia

Australia is a signatory to a number of international agreements which propose energy conservation and greenhouse gas reductions (Australian Greenhouse Office, 1998 and 2002). There have been studies examining transport consumption (Hensher *et al*., 1990; Lenzen, 1999; Perkins, 2001), building design principles (Fay *et al.,* 2000; Pullen, 2000; Treloar *et al.,* 2000), and the efficiency of household appliances (National Appliance and Equipment Energy Efficiency Committee, 2001). There have been a few studies examining household energy consumption in Australia (Common and Salma, 1992) at broader spatial levels. There has, however been little attention given to understanding the behaviour of, or factors that influence household consumption decisions (Ironmonger *et al*., 1995).

One of the few studies examining the factors that influence household consumption patterns in Australia analysed domestic electricity use in Sydney in a study carried out using 1985 data (Poulsen and Forrest, 1988). Prophetically in view of the recent Adelaide study, this used data on the ninety-nine account districts making up the then Sydney County Council area, aggregating population and dwelling characteristics from Census Collector Districts (CCDs) to fit these districts. This study found that electricity consumption by households was determined by whether gas was available, dwelling type, dwelling size and family income. An initial attempt to look at socio-demographic variables in terms of family structure (i.e. the proportion of households which consisted of nuclear families) had little influence. This was probably because of the preliminary and exploratory nature of such an analysis and its dependence on what data was available from the Census.

In addition, Ironmonger *et al*., (1995) studied the economies of scale (EOS) in both energy use and expenditure on energy, and the influence of household type. They found that EOS meant small households use more energy per adult to maintain an equivalent level of production. They concluded that the increasing number of small households would therefore increase total residential energy use.

The Determinants of Household Energy Use

From this literature review, it would appear that the main determinants of the way households use energy in the home are:

- micro-climate;
- dwelling type;
- age and type of construction;
- dwelling size;
- household size;
- household income.

These fall into the two broad categories of 'the energy efficiency of dwellings and the consumption behaviour of households' (Poulsen and Forrest, 1988, p. 337).

However, there is a basic problem of a high degree of intercorrelation among these variables, or 'multicollinearity'. This means that one feature of the household or dwelling which is important in determining energy consumption is highly correlated with another. For example, Table 1 shows the average weekly expenditure on domestic fuel and power, by household income quintile groups from the ABS Household Expenditure Survey of 1998-99 (ABS, 2000). While the amount of money spent on fuel and power rises from the lowest income quintile to the highest quintile, the average household size also rises from 1.52 to 3.33. Medium and high-density dwellings such as flats, units and villas are more likely to be occupied by small households. If age is important in energy use, then it should be noted that the average age of the 'reference person' in the household is 59 for the lowest income quintile compared with an average age of 48 for all households.

TABLE 1: Average Weekly Expenditure on Domestic Fuel and Power ($) by Household Income Quintile Group, Australia 1998-99

	Gross Income Quintile					
	Lowest 20%	Second Quintile	Third Quintile	Fourth Quintile	Highest 20%	All Households
Household Expenditure on Domestic Fuel and Power ($)	12.85	15.87	17.72	19.85	23.08	17.87

(source: ABS, 2000)

The Empirical Data from Adelaide

The unique nature of the Adelaide pilot project (Troy *et al.*, 2002) was its comprehensive measurement of the energy and water demands of different kinds of urban localities. A part of this was the recording and analysis of the day-to-day energy and water use of the residential population. Further, the areas chosen represented localities of different socio-economic character, and therefore, inferences could begin to be made about the determinants and consequences of energy and water use by different kinds of households in different types of dwellings. This provides a powerful base for more directed research at this small area level (the Census Collector District) into the determinants of energy use in the home.

The delivered electrical energy consumption for properties in the six case study areas in Adelaide were obtained from the records of the Australian GasLight Company (AGL) in kilowatt-hours (kwh) for 1999-2000 and 2000-2001 from a sample of properties in each case study area. This was necessary as the database was based on customer records rather than property records and so had to be individually interrogated to extract the data. In those case study areas with a substantial number of dwellings, a sample of 30 dwellings was randomly selected. Where there were less than 30, all residential properties were extracted.

The delivered gas consumption for each dwelling connected to a gas supply in the case study areas were obtained from Origin Energy. Not all properties in each case study area were connected. This energy was measured in Gigajoules (GJ).

It is apparent that properties that are not connected to a gas supply will use more electricity — a factor that Poulsen and Forrest (1988) built into their analysis. Therefore, the consumption of electricity and gas needs to be put onto a comparable basis. This is done by converting kilowatt-hours and Gigajoules into the primary energy equivalent needed to generate, process and distribute electricity and gas. This is measured in Gigajoules.

TABLE 2: Estimated Annual Primary Energy Consumption (GJ) by Domestic Consumers in Six Case Study Areas in Adelaide, 2000-2001.

	Adelaide City	Brahma Lodge	Hawthorn	Hindmarsh	Norwood	Woodcroft
Electricity Consumption (GJ)						
Total	*10,573*	*30,774*	*10,989*	*4,691*	*17,118*	*10,946*
Per Property	54.5	62.9	87.2	42.6	62.9	52.4
Per Capita	33.9	23.8	30.3	22.2	31.7	18.1
Gas Consumption (GJ)						
Total	*386*	*14,291*	*3,859*	*1,464*	*3,878*	*5,317*
Per Property	20.3	37.3	42.9	21.9	24.2	46.3
Per Capita	13.5	13.8	17.2	9.9	12.1	16.0
Total (GJ)						
Total	*10,959*	*45,065*	*14,848*	*6,155*	*20,996*	*16,263*
Per Property	74.8	100.2	130.1	64.5	87.1	98.7
Per Capita	47.4	37.6	47.5	32.1	43.8	34.1

(derived from Troy *et al*, 2002)

Table 2 shows the results of these calculations. The average electricity and gas consumption per property in terms of primary energy is taken from the records of domestic consumers. All dwellings are connected to electricity supply, but only a proportion of them to gas. Accordingly the gas consumption per property and *per capita* is shown for those dwellings only. It was not possible to do the reverse and identify dwellings connected to electricity only. Hence total domestic energy consumption is represented in the bottom lines of the table. It is to those totals that we now address our attention.

The figures for energy consumption per property range from 64.5 GJ in Hindmarsh to 130.1 GJ in Hawthorn. For the other four areas energy consumption per property ranges from 74.8 to 100.2 GJ. However, the *per capita* figures range from 32.1 in Hindmarsh to 47.5 Gigajoules in Hawthorn, with the four intermediate areas in the relatively narrow range of 37.6 to 47.4. These figures can only be calculated by dividing total domestic energy consumption by the population living in each case study area at the 2001 Census.

The *per capita* figures reflect the median household incomes for each area, as recorded in the 1996 Census, and this is even more so when the differences of household size in the case study areas are taken into account (Holloway *et al.*, 2002). These relationships will be further clarified when analyses of the case study areas are made using more current data on income and household size from the 2001 Census.

So what about the behaviour of households? How is this behaviour in part conditioned by the kind of dwellings they live in? Dwellings range in size, configuration, materials, and degree of insulation. On a small area basis, the only differentiation that could be made was between separate houses and other residential dwellings from the Census. Table 3 presents the domestic energy consumption figures for the six case study areas in this manner.

TABLE 3: Estimated Annual Primary Energy Consumption (GJ) by Domestic Consumers per House and Other Residential Dwelling in Six Case Study Areas in Adelaide, 2000-2001

	Adelaide City	Brahma Lodge	Hawthorn	Hindmarsh	Norwood	Woodcroft
Estimated Annual Primary Energy Consumption (GJ)						
Per House	NA	100.2	130.1	70.0	100.8	98.7
Per Other Residential Dwelling	74.8	NA	NA	60.4	73.4	NA

(derived from Troy *et al*, 2002)

Although the houses in the six case study areas were built at different times and with different building materials, and vary in size, their annual consumption of primary energy lies in the range 70.0 to 130.1 GJ, with these two extremes again being found in Hindmarsh and Hawthorn. Three other case study areas have values which cluster round the 100 Gigajoule mark.

As expected the figures for dwellings other than separate houses are smaller, and could only be reasonably estimated for three of the case study areas. Obviously these lower values also reflect the smaller size of these kinds of dwellings, and the smaller households living in them.

Apart from this distinction between houses and other residential dwellings, the materials and method of construction of dwellings vary at different times. The Adelaide pilot study estimated the embodied energy contained in dwellings built in four periods resulting from the variation in such characteristics as the height of ceiling, concrete or timber flooring, clay or concrete roofing, and double brick or brick veneer construction. These circumstances would obviously affect the use of energy for heating or cooling. In fact, recent building codes have been introduced to improve the energy efficiency of new dwellings.

Further Research and Policy Implications

The Adelaide pilot project was the first attempt to marry energy consumption figures for households with Census Collector Districts (CCDs) in order to establish the characteristics of energy use in different kinds of urban development with various residential populations. The results are sufficiently encouraging and informative to enable more effective selection of further areas and the focussing of data collection and analysis to draw out the character and influence of the most important determinants of household energy consumption and their correlation in these areas.

Accordingly one avenue of further research is to pursue this kind of analysis in terms of the kind of step-wise multiple regression followed by Poulsen and Forrest. The Adelaide experience shows that this would enable more detailed consideration of the variables involved in influencing household consumption of energy. This could be done by more exhaustive work on a more comprehensive range of data, enabling more incisive conclusions to be drawn. This would further marry the property database which gives good details on the physical characteristics of the dwelling with the energy consumption characteristics of households and with data on the socio-economic characteristics of the population derived from the Census.

In pursuing this direction, it is however important to aim at a level of generalisation that does not distort the integrity of the data sets and their connection or association. This is also relevant for policy development, which has only broad instruments to influence behaviour and the nature of the built environment.

All this, however, is macro- or meso-analysis from desktop data. It lacks the crucial dimension of primary data on the characteristics of energy use by households and why this is so. To probe the determinants and consequences of energy use in the dwelling, it is necessary to carry out household interviews. This could more clearly establish the reasons for the behaviour of different kinds of households in using energy. While this is an expensive and time-consuming exercise it is an essential companion of small-area analysis.

The data extracted from the Adelaide pilot project clearly shows the intertwined influences of household and dwelling characteristics on energy use. *Per capita* use of energy does not show wide variation, but that which exists does appear to reflect household income (Holloway *et al.*, 2002). There is less use of energy in dwellings other than separate houses, but this is associated with smaller household size.

It is likely that the use of energy in the home will become more of an issue in public policy, either in terms of the conservation of natural resources or in limiting the generation of greenhouse gases. Appropriate responses lie either in the field of regulation or pricing. Regulation is already used to influence the kind of construction, materials and insulation of dwellings. This control needs also to consider the energy embodied in different kinds of buildings. Its effectiveness also needs to consider the resultant behaviour of households in using energy. The further research outlined in this paper would contribute to fine-tuning of these regulatory policies, and deciding the relative contribution and complementarity of regulatory and pricing measures. It would also enable the development of urban management tools to guide more sustainable development.

The behaviour of households in using energy can also be influenced by pricing arrangements. How to design an equitable and effective pricing regime is difficult. It would also have to take into account the differences in energy use brought about by varying climatic conditions. However, one principle flowing from the Adelaide project is to have a stepwise tariff with price per unit increasing above a basic threshold, which should comfortably cover the essential, needs of all households. Conversely, extravagant use of energy would attract a premium. It may be that special attention might be needed for some consumers such as the heating subsidy for elderly people used in the United Kingdom. However, that kind of measure could remain as an option at first, while experience in a more general tariff structure is digested.

If this principle was adopted, it might be applied to the use of electricity, whose generation involves more use of primary energy and more production of greenhouse gases than does gas. Gas is also used almost entirely for the basic requirements of water and space heating, and cooking. However, even this theme would need some variation where there is extensive use of electricity for air conditioning in hot climates.

Finally, this direction of research into the characteristics of energy demand by urban localities will progressively improve urban management. It will more adequately define the contribution of social, demographic and cultural factors to energy demands in sub-metropolitan areas and the way in which they correlated with the characteristics of the built environment in particular places. This will allow urban planning and service agencies to better appreciate and estimate the energy demands arising from proposed changes to urban places. This could be in the form of particular development proposals or in defined areas of urban development or change. It may be that thresholds can be set for particularly sensitive localities or for certain kinds of development to limit the use of energy and the production of greenhouse gases.

Conclusion

The exploratory nature of the Adelaide pilot project has two related dimensions. One was to test the feasibility of interrogating and associating data sets in order to provide a detailed and comprehensive description of the characteristics of water and energy consumption in urban areas. The other was to provide a foundation from which further research projects could be designed to help a transition to more sustainable forms of urban development.

This paper has been concerned with the issue of more adequately defining the determinants of everyday energy use in the home. These fall into the two areas of the kinds of dwellings being used and the behaviour of its residents. However, there is a high degree of intercorrelation among these variables which is difficult to disentangle, but also needs to be accomplished at a level of generality that maintains the integrity of the data, and is helpful to appropriate policy responses.

Two research projects seem to come to the fore as worth exploring. One is to carry forward the data collection and analysis used in the Adelaide pilot project to encompass more forms of residential development, and more detailed analysis of the relationships between energy consumption, household characteristics and dwelling type. This would be based on the Census Collector District. This could be carried out anywhere in Australia provided the property database supported the analysis, as it did in Adelaide. The other research project is a complementary one and depends on surveys to probe household behaviour with respect to energy use. This latter project would help define not only the characteristics and determinants of individual household use, but enable correlations with how this might reflect energy conservation measures in the construction and use of the dwelling.

These research directions and projects would provide much more information on how appropriate pricing policies and regimes might be developed to reduce the use of energy, and limit the emission of greenhouse gases. They would also enable the development of urban management instruments to shape and guide policies about urban planning and regulation to deal with localities and areas of development and redevelopment. Crucially, this kind of research addresses the need for understanding and policies about how the household, the urban locality and citywide policy might contribute to the conservation of energy and the limitation of greenhouse gases. This body of research establishes a focus, fulcrum and foundation to help the transition to more sustainable use of energy in Australia’s cities.

Notes

1. Folk knowledge refers to the informal measurement techniques that people use to conserve energy. However, these informal techniques are often inaccurate and individuals can incorrectly estimate the savings produced. That is, the diminished energy savings are not from a lack of information, but rather a lack of accurate information. In folk knowledge, adoption of energy conservation measures are more likely if the information is heard from friends or neighbours or based on hearsay or personal testimony rather than if it comes from energy conservation experts (for a more detailed review see Guerin *et al.*, 2000:65-66).

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