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A dwelling-level investigation into the physical and socio-economic drivers of domestic energy consumption in England

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HIGHLIGHTS

- We examine the drivers of domestic energy consumption.
- We examine the impact of domestic energy efficiency measures on energy use.
- Dwelling type and size affect electricity and gas consumption.
- Income level, tenure and number of resident adults influence energy use.
- Energy efficiency measures lead to significant energy savings for households.

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ABSTRACT

The UK Government's Department for Energy and Climate Change has been investigating the feasibility of developing a national energy efficiency data framework covering both domestic and non-domestic buildings. Working closely with the Energy Saving Trust and energy suppliers, the aim is to develop a data framework to monitor changes in energy efficiency, develop and evaluate programmes and improve information available to consumers. Key applications of the framework are to understand trends in built stock energy use, identify drivers and evaluate the success of different policies. For energy suppliers, it could identify what energy uses are growing, in which sectors and why. This would help with market segmentation and the design of products. For building professionals, it could supplement energy audits and modelling of end-use consumption with real data and support the generation of accurate and comprehensive benchmarks. This paper critically examines the results of the first phase of work to construct a national energy efficiency data-framework for the domestic sector focusing on two specific issues: (a) drivers of domestic energy consumption in terms of the physical nature of the dwellings and socio-economic characteristics of occupants and (b) the impact of energy efficiency measures on energy consumption.

1. Introduction

Rapid progress in built stock energy efficiency is needed as Government moves to develop carbon budgets and targets following the Climate Change Act, 2008. Better information about the patterns and drivers of energy consumption, and the impact of energy efficiency measures in the built stock, is needed to underpin both existing and future programmes of action. Government and its agencies, the property sector, energy and energy services providers and users, all need accurate information on which to base decisions and measure results. Collecting such data in the conventional way through on-the-ground surveys and measurements is time-consuming and expensive. Data frameworks, based on existing data sources, offer a practical alternative. They are powerful tools through which a range of existing data sets relating to the building stock can be matched with information on energy meter points and consumption and interpreted at disaggregated levels.

The UK Government's Department for Energy and Climate Change (DECC) has been investigating the feasibility of developing a National Energy Efficiency Data-framework (NEED) covering both domestic and non-domestic buildings. Working closely with the Energy Saving Trust and energy suppliers, the aim is to develop a data framework as a means of understanding changes in energy efficiency, developing and monitoring programmes and improving information available to consumers. Key applications of the data framework are to understand trends in built stock energy use and identify their drivers, and to evaluate the success of

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different policy levers. For energy suppliers, it could identify more accurately what energy uses are growing, in which sectors and why. This would help with market segmentation and the design of products. For building professionals, it could supplement energy audits, help model end use consumption with real data and support the generation of accurate and comprehensive benchmarks together with an appreciation of their variability.

NEED provides the largest data source currently available for analysis of energy consumption at the building level. Previous evidence in the domestic sector has been derived from surveys including the English Housing Survey (Department for Communities and Local Government, 2012) and small scale technical monitoring trials (Chapman et al., 1985; Edwards, 1990; and Summerfield et al., 2007 for example). The use of existing administrative data sources has enabled this rich data source to be constructed at relatively low cost. A unique aspect to Phase 1 of NEED was the exclusive access granted to dwelling attribute data held and maintained by the Valuation Office Agency for property taxation purposes. Rather peculiarly, and unlike practice in many other countries, such data are not publicly available in England and Wales. Access to these data was strictly controlled: any analysis that involved VOA data had to take place on VOA premises and the output was checked and anonymised before release so that no individual dwelling could be identified.

Phase 1 of NEED contains physical and socio-economic details of a large sample of residential dwellings in England, together with gas and electricity consumption data. The initial aims were twofold: to develop a greater understanding of the drivers of domestic energy consumption in terms of the physical nature of the dwellings and socio-economic characteristics of occupants, and to evaluate the impact of energy efficiency measures on energy consumption.

2. Background

According to Brent Ritchie et al. (1981) the first major empirical study of household energy consumption was undertaken in 1973 and there have been many energy studies since then that have focussed on programmes for reducing energy consumption and possible explanations for consumption levels, including dwelling attributes, appliance ownership and demographics. In these latter studies the main explanatory factors were found to be type of water and space heating systems, full-time use of home, dwelling size, household income and number of occupants. At the time their paper was published, only a few studies used actual consumption data as the dependent variable and most studies had a limited subset of potential predictor variables. Brent Ritchie et al. (1981) found that external temperature, dwelling size, mean thermostat setting, presence of a fireplace and whether the home was part of a multiple occupancy building all affected energy consumption. With regard to demographic factors, family size income level and age of head of household were significant.

In terms of method, according to Swan and Ugursal (2009), regression analysis is a widely used method of examining customer energy billing or metering information in order to determine the drivers of energy consumption. Input variables that describe the physical characteristics of the dwellings and the socio-economic characteristics of the occupants are regressed against consumption data. These models regress the aggregate dwelling energy consumption onto parameters or combinations of parameters which are expected to affect energy consumption. The models are evaluated based on goodness of fit. Hitchcock (1993) argued for an integrated systems model of household energy consumption that includes physical dwelling attributes and human behavioural factors and indeed most domestic energy consumption studies have incorporated both human and physical aspects of energy consumption.

With regard to the main drivers of domestic energy consumption, Dresner and Elkins (2006) reported a correlation of 0.019 between energy use and household income when using data from the 1996 English House Condition Survey (now the English Housing Survey) and 0.207 when using data from the 1999–2000 Family Expenditure Survey. Not only are these correlations very different, they reveal a negligible to minor relationship between energy use and income level. Using spatially aggregated data, Druckman and Jackson (2008) found that when UK neighbourhoods are categorised by socio-economic characteristics they display widely different patterns of consumption. They analysed mean energy consumption at census output area level for 2004 and 2005 and found a positive relationship between energy use and income level ($r^2=0.27$; $p<0.01$); a stronger relationship than that identified by Dresner and Elkins. They also found that dwelling type, tenure, number of people per household and urban/rural location are important and that different segments of the population consume different quantities of energy depending their socio-economic characteristics. Focusing on property size, Yohanis et al. (2008) found, perhaps unsurprisingly, a clear positive correlation between annual electricity consumption and floor area. In the UK, detached dwellings are typically larger than semi-detached dwellings which are, in turn, larger than terraced houses. So when the stock was classified in this way they found the range of annual energy consumption for detached dwellings to be 3.57–5.17 kW h/m^2, for semi-detached dwellings it was 3.44–4.59 kW h/m^2 and for terraced houses it was 2.50–3.90 kW h/m^2. Santin et al. (2009) found that physical dwelling attributes were the major determinants of energy use but occupant characteristics and behaviour also affected energy use. Specifically, detached dwellings consume more energy than other types of dwellings, followed by semi-detached, end of terrace, mid-terrace dwellings, maisonettes and flats. It should be noted that, this study, the standard deviation for each type of dwelling was high. Energy use in better insulated houses is lower than in less insulated houses but the standard deviations were also large. Santin et al. (2009) also provide a useful review of previous studies that have investigated the drivers of energy consumption. Summarising, they found dwelling design, dwelling age, insulation, heating system and household age/size/income to be the main drivers. Firth et al. (2010) constructed a domestic energy model that classified dwellings according to their age and built form: 47 archetypes were constructed. Using data from the Meteorological Office, the 2001 Census, the English House Condition Survey, the Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP) and the Building Research Establishment's Domestic Energy Model (BREDEM), they found

Table 1
Average domestic annual energy consumption from main fuel types.
Source: Firth et al. (2010).

	End-terrace	Mid-terrace	Semi-detached	Detached	Flat (purpose-built)	Flat (other)	All dwellings
Gas (kW h)	18,788	15,531	17,727	24,175	9416	15,300	17,449
Electricity (kW h)	4,528	4,448	4,439	5,084	4248	4,931	4,574