DWELLING TEMPERATURE AND ENERGY USE SINCE 1990: RESULTS FROM A LONGITUDINAL STUDY OF LOW ENERGY DWELLINGS IN THE UK

AJ Summerfield†, RJ Lowe, HR Bruhns, JA Caeiro, A Pathan, and T Oreszczyn

Bartlett School of Graduate Studies, University College London UK

ABSTRACT

A study from 2005-2007 has been undertaken of 18 'low-energy' dwellings in Milton Keynes, UK, originally monitored for temperature and energy consumption from 1989-1991. Results were compared under standardized daily external conditions of 5ºC. The follow-up study found no evidence of change in mean living room temperatures of 20.0ºC (95% Confidence Interval:19.7-20.3) and weak evidence for a decline to 19.3ºC (CI:19.1-19.6) for main bedrooms. On average there was a 10% increase in gas consumption over 15 years to 70kWh/day (95%CI:60-80) and overall electricity usage rose by 30% to 15kWh/day (CI:13.5-16.5). Dwellings were classified into three groups of low, middle, and high energy users in 1990. At follow-up, the high group accounted for most increases in energy use, consuming more energy than the other two groups combined; their gas usage rose by 20% to 130kWh/day (CI:110-150), electricity by 75% to 28.5kWh/day (CI:25.5-31.0). On average the high group comprised dwellings that were larger, had been extended, and whose occupants had higher incomes than the two other groups. The results suggest that research for development of energy policy, including building regulations, should focus both on how energy is currently used and on households where largest future increases and most are likely to occur.

KEYWORDS

Domestic, Energy Efficiency, Energy Trends, Longitudinal Survey

INTRODUCTION

The UK government aims to achieve a 60% reduction in carbon emissions by 2050 (Department of Trade and Industry 2007). Since 1990, total CO2 emissions from the UK have reduced by nearly 6% to 153Mt of carbon in 2005, with the domestic sector estimated as contributing 27% (41.2 Mt). While emissions from the sector are 2% lower than in 1990, the figures include the effect of an almost 30% fall in the carbon content of electricity generation over the period (Dept. of Trade and Industry 2007). More to the point, annual energy consumption in the domestic sector has risen since 1990 by 20% (565TWh/yr). Even on a per household basis, by 2004 gas consumption had risen by 17% (to 15.5MWh/yr) and electricity by nearly 10% (to 4.5MWh/yr), while other energy sources, such as solid fuels, declined over the same period (Dept. of Trade and Industry 2006).

These figures illustrate a real difficulty in accurately modelling energy usage in the domestic stock – and thereby in forming effective energy policy – in that changes in consumption patterns arise from multifarious physical and social influences on the building stock and its occupants; including greater prevalence of gas central heating, higher levels of insulation, building fabric deterioration and renovation, as well as the impact of changes to building regulations. This has been accompanied by the impact of sociodemographic trends, such as an aging population, fewer people per household, and relative changes in disposable income, that may further directly and indirectly affect energy use.

It is essential to unravel the interactive and dynamic effects of socio-technical factors over time, in other words the changing relationships of the occupant with the building performance and operation. One

† Corresponding Author: *Tel: + 44 27679 865, Fax: + 44 27679 7467*
E-mail address: a.summerfield@ucl.ac.uk

common example of such interaction is usually termed ‘take back’ factor, whereby improvements in energy efficiency to existing dwellings often result in higher thermal comfort levels rather than simply lower energy consumption (Milne and Boardman 2000). These phenomena may have considerable implications when applied to the domestic stock at the national scale. Given average winter temperatures of around 5-6˚C over the heating season in the UK, the demand for space heating may be estimated to increase by around 10% for every degree increase in internal temperatures. Shorrock and Utley (2003) have suggested that in centrally heated homes mean internal temperatures for the 6 months of winter have increased from 17.4˚C in 1990 to 19.1˚C in 2001 with the further expectation that this rise would eventually stabilise at approximately 21˚C for well insulated homes. Unfortunately empirical temperature data from large scale studies to support if and when saturation will occur are scarce. The most comprehensive study, in terms of the number of properties visited and range of rooms monitored, remains the spot measurements taken in the 1981 UK Nation Field survey of House Temperatures (Hunt and Gidman 1982). More recently the Warm Front study has focussed on households with conditions associated with fuel poverty, with occupants typically having low income and aged over 60 or with young families. Over 1,600 dwellings across the UK were intensively monitored over a period of typically 2 weeks in the winters of 2001-2003 (Oreszczyn et al. 2006). Under standardised external conditions of 5°C, it was found that median daytime living room temperature was 19.1°C and the median standardized night time bedroom temperature 17.1°C.

The current study is part of the Carbon Reduction in Buildings (CaRB) project that is aimed at finding ways to reduce carbon emissions from the UK building stock. CaRB intends to use empirical data from longitudinal studies of temperature and energy usage to detect trends and assist with the development of socio-technical models for the domestic sector. Rather than rely on initiating a longitudinal study from scratch, where inevitable delays would be incurred before significant trends could emerge, the CaRB project has also sought suitable prior studies with accessible temperature, energy, and social data to serve as a baseline survey.

One such study in Milton Keynes, a low density town located about 75km North-West of London, was undertaken from 1989-91 (here referred to as *MK 1990* or *baseline*). The dwellings essentially follow conventional UK housing design but have higher standards of energy performance than were required by the building regulations at that time. They incorporated energy efficiency features, such as increased floor and wall insulation, double-glazing, and condensing boilers, so that they broadly corresponded to building standards of a decade or more later (Edwards 1990). A sub-sample of 29 dwellings were monitored for hourly temperature and energy consumption. It is assumed that the baseline data in 1990 already reflect any take-back factors derived from the occupants’ adjustment to living in new well-insulated homes (say, in comparison with their previous accommodation).

This paper updates previous work reported in our initial pilot study (Summerfield et al. 2007). The following hypotheses for changes since then were advanced:

- Internal temperatures may have increased in line with a demand for higher comfort levels
- Energy, both gas and electricity, consumption will have increased to reflect changes in temperature and physical changes to the dwelling (such as additions or extensions, and more appliances).

METHODS

Baseline and Follow-up surveys

The original study monitored hourly gas and electricity consumption, internal temperature and relative humidity data for living room and main bedroom for 29 dwellings, as well as external weather data. A period of 18 months lasting from 6 January 1989 to 30 September 1990 was selected on the basis of having the most reliable energy and temperature data collected from the study dwellings. A limited dataset from the social survey was also recovered. From early 2005 the follow up survey was initiated by CaRB in 2 stages with 18 respondents recruited from the 29 dwellings in the detailed MKEP 1990 sub-study. Apart form those occupants unable to be contacted, the reasons given for non-participation were ‘lack of availability due to work commitments’, ‘being away during the start of the study period’, ‘moving to another home’, and ‘illness’. Building and interview surveys were conducted and data-loggers for half-hourly readings of temperature and relative humidity were placed (at minimum) in the living room and main bedroom of each dwelling. Gas and electricity meter readings were taken on an approximately monthly basis.

Statistical Analysis

The final sample at both time points comprised 18 centrally heated dwellings. To enable a comparison under standardised winter conditions (and without needing annual data), simple linear regression models were fitted for each dwelling with daily mean external temperature (T_{ex}) as the predictor (independent) variable with outcome (dependent) variables of daily internal temperatures, gas, and electricity usage. As illustrated in figure 1, the regression model was restricted to T_{ex} < 13°C, except for electricity usage, with estimate values obtained for T_{ex} = 5°C (Figure 1).

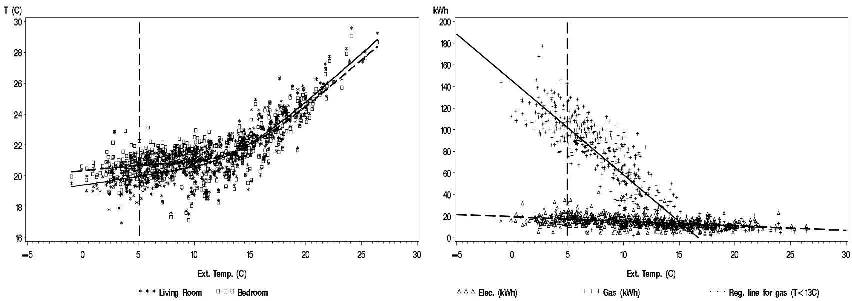

Figure 1. Daily internal temperature (left) and gas and electricity use (right) vs. external temperature for a sample dwelling at baseline 1990.

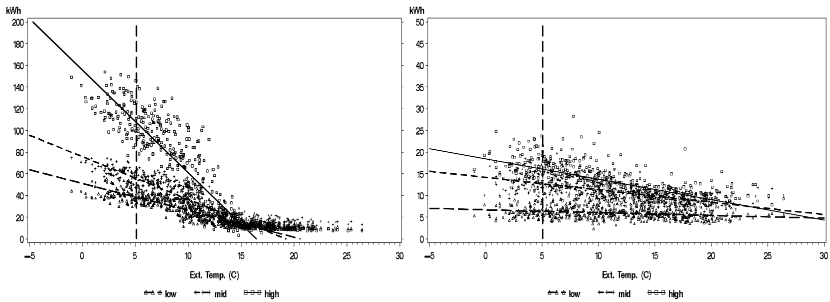

Figure 2. Daily gas (left) and electricity (right) use vs. external temperature at baseline for low, mid, and high total energy consumers, with energy consumption estimated at T_{ex} = 5°C for each group.

Since the distribution of energy consumption was found to be skewed, dwellings were then grouped into thirds based on their total energy consumption in the 1990 study, and referred to as the low (n=6), mid (n=6), and high (n=6), energy groups. Once a dwelling was classified according to its energy consumption in 1990, it remained in the same group throughout the analysis to simplify interpretation of the results. Thus any change detected in a group has occurred to the same group of dwellings from baseline to follow-up studies. The same process as above of fitting regression models was repeated to obtain results for estimated energy consumption of each group (figure 2) for both time points under the same standard conditions of daily T_{ex} = 5°C. All statistical analyses were carried out using SAS version 9.1.

Results

Dwelling and Socio-demographic characteristics

From table 1, the number of people per household has declined from 2.7 to 2.5, with a marked decline in the number of children (≤16 years). Just over half the sample are detached houses (n=10) and a quarter semi-detached (n=5), compared with 22% and 32% respectively across the UK (Shorrock & Utley 2003). The heated floor area of dwellings (that is, excluding unheated extensions, such as conservatories) has increased by 5% to 109m^2. The ownership of certain appliances, such as tumble dryers, televisions, and computers, has increased substantially.

Table 1 Socio-demographic and dwelling characteristics

	Baseline (SD)	**Follow-up (SD)**
Occupants per dwelling	2.7 (0.1)	2.5 (0.1)
Children (<16yrs) per dwelling	1.0 (0.1)	0.30 (0.05)
Annual hhld. income (‘000s GBP)	-	53 (25)
Area per dwelling (m^2)	104 (3)	109 (4)
Bedrooms per dwelling	3.1	3.2
Tumble dryers per dwelling	0.1	0.5
Dishwashers per dwelling	0.1	0.5
Televisions per dwelling	1.2	1.5
Computers (incl. laptops). per dwelling	-	1.6

Using estimates derived from regression models, under standardised external conditions (T_{ext} = 5°C) average living room temperatures have not changed significantly from baseline at 19.9°C (with 95% confidence interval of 19.8 to 20.0°C) to 20.0°C (95%CI: 19.7 to 20.3°C) at follow-up. There was weak evidence for a decline in bedroom temperatures from 19.7 (95%CI: 19.6 to 19.8) at baseline to 19.3 (95%CI: 19.1 – 19.6) by follow-up.

Figures 3 to 5 illustrate changes in daily energy usage estimated at T_{ext} = 5°C that have occurred from 1990 to 2005 averaged over all dwellings and for the 3 energy groups. With no evidence of overall change or change in the low and mid groups, the high energy group had a increase in total energy consumption, from 124 (95%CI: 121 to 127) to 156kWh/day (95%CI: 132 to 180), corresponding to a rise in carbon emissions by this group of 20%. When total energy is disaggregated by fuel, the evidence for an increase in overall gas consumption (figure 4) was not significant (baseline: 65kWh/day 95%CI: 64 to 66, follow-up: 70kWh/day 95%CI: 60 to 80), but considered separately the high energy group used 20% more gas by 2005-7 monitoring (130kWh/day with 95%CI: 110 to 150 from 109 kWh/day 95%CI: 107 to 111 at baseline). The change was not statistically significant when gas usage was normalised for floor area (figure 5, left), reflecting that all the increase in floor area via heated extensions to the dwellings occurred in the high energy group (148m^2 - 160m^2).

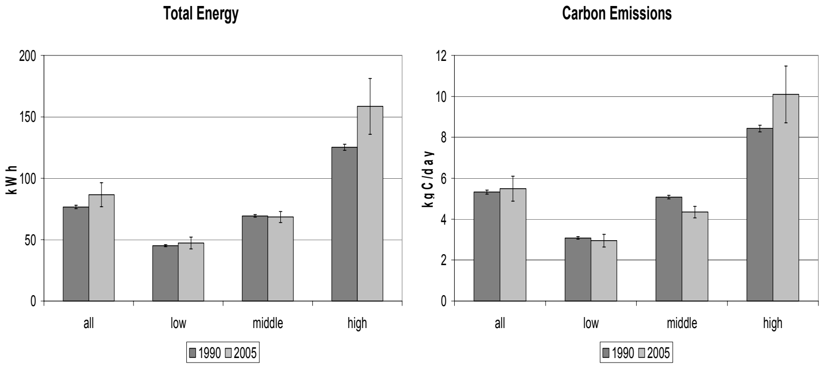

Figure 3. Daily total energy usage and consequent carbon emissions (95%CI) for 1990 and 2005 by energy group (at external T=5°C).

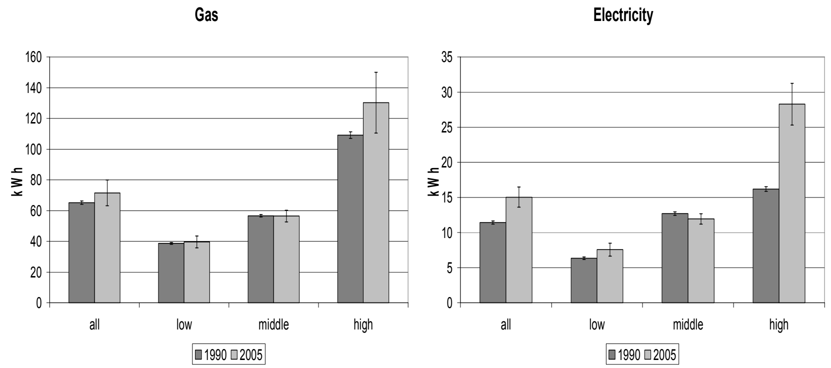

Figure 4. Daily gas and electricity usage (95%CI) for 1990 and 2005 by energy group (at external T=5°C).

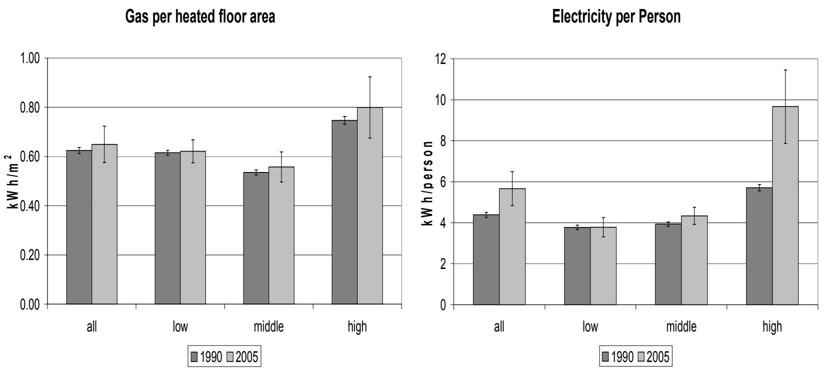

Figure 5. Daily total energy usage and consequent carbon emissions (95%CI) for 1990 and 2005 by energy group (at external T=5°C).

For all dwellings, electricity usage had risen since 1990 by more than 30%; from 11.2 kWh/day (95%CI: 11.0 to 11.4) to 15.0 kWh (95%CI: 13.5 to 16.5) by follow-up. This was again almost entirely due to the 75% rise by high energy users from baseline to 28.5 kWh (95%CI: 25.5 - 31.0). This pattern remained the case when considered on an energy per occupant basis (figure 5, right).

CONCLUSIONS

This longitudinal study of 18 *low-energy* dwellings in the UK investigated changes in internal temperature and energy usage from baseline (1989-1991) to follow-up (2005-2007) under standard winter conditions of 5°. These well-insulated homes were found to have living room temperatures of 20.0°C (95%CI: 19.7 to 20.3°C) and bedroom temperatures of 19.3 (95%CI: 19.1 to 19.6). While the almost 10% increase in daily gas usage was not found to be statistically significant at 70kWh/day (95%CI: 60 to 80), electricity consumption rose by 30% to 15kWh (95%CI: 13.5 to 16.5) at follow-up. This essentially offset the reduced carbon content of electricity generation over the same period. The prevalence certain appliances, such as tumble dryers and dishwashers increased markedly.

When the results were analysed with dwellings classified into three groups, of high, mid, and low energy users according to the estimated consumption from the baseline data, a consistent pattern emerged whereby high energy users accounted for almost all of the increases observed in the overall statistics. Unsurprisingly this tends to correspond with larger homes and with household with higher incomes. Gas use by the high energy group rose by 20% to 130kWh/day with (95%CI: 110 to 150), while their electricity usage jumped by 75% to 28.5 kWh (95%CI: 25.5 to 31.0). The gas consumption, that is effectively the space heating demand, may be partly explained by the increased in heated floor area of these homes (which did not occur in the other groups), but there was no evidence of increased living room temperatures. In summery the high energy group not only accounts for more than half (57%) of the energy used in 2005 but this is three times more than the low group (46kWh/day, 95%CI: 42 to 50) and double that of the middle group (67kWh/day, 95%CI: 64 to 72).

There was weak evidence that on average daily gas consumption under the standard winter conditions had increased by 10% to 71 kWh/day (95%CI: 63 to 80), while electricity usage was more than 30% higher at 15 kWh/day (95%CI: 13.6 to 16.5). No evidence of change over the 15 years in average living room temperatures (20.1°C (95%CI: 19.8 to 20.3) and weak evidence for a slight drop in main bedroom temperatures 19.3°C (95%CI: 19.1 to 19.6)).

The main strength of this study lies in the detailed energy and building data collected in 1990 that forms the baseline survey. Although the sample should not be regarded as being representative of the national building stock, with an over-representation of detached dwellings and higher income levels in the MKEP sample, the occupants appear to have undergone broadly similar social and demographic changes. Moreover the results here appear to be consistent with the skewed energy consumption distribution that is evident in national figures, whereby the top 30% of households by income spend (and by implication use) more than all other households combined (Shorrock & Utley 2003). The small sample size has also led to a lack of statistical power, that when combined with the less detailed energy measurements obtained from monthly meter readings in the 2005 study, have reduced the range of factors that could be analysed.

In spite of these limitations, there is great value in studying this specific group of dwellings that represented best practice for the symbolically important year – in Kyoto Protocol terms – of 1990 and which were roughly a decade ahead of their time with respect to building regulation standards. Hence they also provide an indication of what might be expected a decade from now, from dwellings of an equivalent standard. The study has shown that some dwellings have remained essentially at 1990 carbon emission levels or below and that for most there was no evidence of a decline in the energy performance of the building. Yet this was not the case for a group of dwellings; the findings indicate that dwellings with high energy usage in 1990, which consisted mostly of larger detached dwellings, were primarily responsible for the increased usage of energy, particularly electricity by 2005. Though unexpected, there appear to be a number of plausible explanations for this effect, and we would expect future studies to yield similar results. Already, however, this study highlights issues regarding the importance of effective targeting of energy conservation measures both to where consumption is greatest and increasing most rapidly.

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