Carbon Emissions and the Case for Joined-Up Research: adding value to household and building energy datasets

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To reach UK objectives for reducing carbon emissions, it is argued that joined-up research on energy use in buildings is essential to develop and support government policy initiatives. The performance based approach introduced in Part-L of the 2006 Building Regulations has further underlined the role of coordinated research to monitor their effectiveness and provide feedback for subsequent revisions. Unfortunately, differences in dwelling classifications systems used in major household surveys currently hinder much of the supporting analysis that might improve SAP and other energy models. The Carbon Reduction in Buildings project has begun a process of integrating or organising existing building energy datasets into a coherent structure for the domestic sector. In addition, it is proposed to archive these for researchers via a building data repository that would facilitate joined-up research more widely.

Keywords: carbon emissions, energy use, building regulations, data repository.

INTRODUCTION

The notion of 'joined-up government' has become an established theme of modern civil administration, whereby in order to address complex issues a "concerted effort is made by coordinating all the arms of government - central and local government and public agencies, as well as the private and voluntary sectors" (Bogdanor and British, 2005). Reducing carbon emissions associated with the buildings in the UK is just such an issue. This paper argues that the corollary of formulating effective joined-up government should be *joined-up research*: the complexity posed by policy related research questions requires analysis that encompasses diverse datasets from numerous sources.

Currently the many additional countervailing influences on energy usage associated with buildings in the UK render this approach all the more timely and essential. They include:

- The direct and indirect impact of climate change on buildings and on their operation, through extreme weather events or restrictions on the provision of services.
- Issues of energy security and increased volatility of energy prices on a global scale.
- Changes in socio-demographic characteristics of households in the UK as well as in the overall profile of economic activity, as has occurred with the aging population or in the decline of manufacturing.
- Rapid technological advances leading not only to a proliferation of appliances that increase the opportunity for energy consumption, but in the changing

nature of usage associated with specific activities, such as entertainment, cooking, or bathing.

- Concomitant advances in monitoring systems that provide opportunities for detailed and unobtrusive measurement of energy usage and building operation as a cost-effective strategy for data collection.

Many of these wider issues have been discussed elsewhere (Department of the Environment, Food and Rural Affairs, 2004) and most notably in the Energy White Paper of 2003 (Department of Trade and Industry, 2003). This document marked a significant change in the approach of the UK Government to energy policy by setting out a long- term strategic vision that incorporated priorities from the environment to security and social issues. In squaring up to meet its numerous commitments, including the key objective of a 60% reduction in carbon dioxide emissions by 2050, the final chapter is devoted to the topic of 'Delivery through Partnership', recognising that the work 'cuts across traditional departmental boundaries' (Department of Trade and Industry, 2003).

To that end, the Energy White Paper announced the formation of the Sustainable Energy Policy Network (SEPN) that links policy units from across government departments, regulators and other key delivery organisations. Indicative of the crucial role for research, membership of SEPN includes The Carbon Trust. In partnership with the Engineering and Physical Sciences Research Council, it has set up Carbon Visions as a coordinated package of university-based research projects to explore how the transition to a low carbon economy can be brought about.

CARBON VISION BUILDINGS AND CaRB

Carbon Vision Buildings focuses on the key objective of identifying ways to achieve a 50% reduction in carbon emissions associated with UK buildings by 2030. One of three components in its programme, Carbon Reduction in Buildings (CaRB), is a 4 year research project involving a cross-disciplinary consortium of UK universities. A key objective concerns developing socio-technical models for energy usage in the UK domestic building stock; that is by unravelling the complex relationship between social and behavioural and technical aspects of buildings. Thus not only is CaRB sited within a framework of coordinated investigation, but the notion of joined-up research lies at the core of its work.

In a previous paper from CaRB (Summerfield *et al.*, 2005), it was argued that building science should consider an epidemiological perspective as an alternative approach to understanding the complexity of influences on energy usage. Termed 'life course building epidemiology', it highlighted another dimension of joined-up research by connecting social and technical data over time that would reveal the important and emerging factors influencing trajectories of energy usage. Specifically, it addressed the need for longitudinal monitoring of buildings, from the design phase through to construction, occupation, and possible alteration and refurbishment phases.

As a pilot longitudinal study in the domestic sector, 16 dwellings from Milton Keynes have been recruited in 2005 for a follow-up survey. They had been monitored for hourly gas and electricity consumption, and internal temperature from 1989-91. At the time, they were considered 'low energy' homes, with extra insulation and condensing boilers (Edwards, 1990). In the resultant comparison over the intervening 16 years, it was found that in spite of increased energy consumption in winter, living room temperatures remained the same and evening temperatures for the main bedroom had decreased significantly (Summerfield *et al.*, 2006). The extent that this reflects changes in the performance of the building fabric or heating system or if differences have occurred in occupant behaviour regarding ventilation (11 participants reported opening bedroom windows throughout winter) remains under investigation.

Such findings illustrate the way long-term changes in performance and operation of energy efficient dwellings may have implications for predicting future energy usage at the national scale. They underline the importance of being able to place findings in context, both in time and with respect to other studies, in a way that potentially provides far greater insight into the complex relationships at work than snapshots provided from ad hoc and disjoined cross-sectional surveys.

CARBON EMISSIONS AND BUILDING REGULATIONS

A second strand of development from the Energy White Paper has produced 'Energy Efficiency: the Government's Plan for Action' that reiterates the theme of joined-up government (Department of the Environment, Food and Rural Affairs, 2004). A crucial element of the plan has been with respect to the most recent Part L of the Building Regulations on the conservation of fuel and power that came into effect in April 2006. This represents a fundamental shift in the compliance methodology that reaches far beyond the incremental tightening of previous revisions. The regulations have been structured around compliance in terms of overall target and design CO_2 emission rates that are calculated using the current Standard Assessment Procedure (SAP) for the energy rating of dwellings (Building Research Establishment and Department of the Environment, Food and Rural Affairs, 2005). It implies that a varying combination of design measures or technical factors will be at work, from changes in south facing glazing ratios to the installation of solar water heating, as long as overall they are predicted to meet the target for carbon emissions.

This flexible performance based approach is expected to generate a far richer array of responses, both in the integration of design solutions and in encouraging partnerships between designers, the construction industry and manufacturers of building materials. Thus the impact of these changes is unlikely to be encapsulated in a future analysis simply as a set of individually prescribed measures, such as might have been evident in the past by assuming maximum U-values of external walls for buildings constructed from a specific date. (U-values refer to thermal transmittance or rate at which heat energy is lost through an area of building fabric to the external environment.)

A range of other factors lend the new building regulations further strategic importance and add to the imperative of detailed research work:

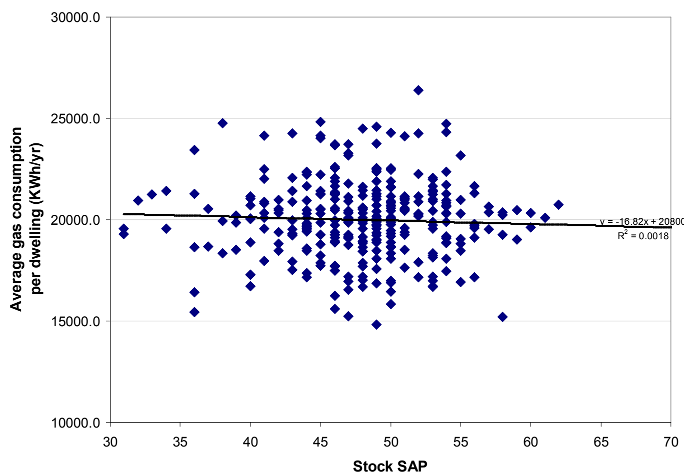
- Measures contained in Building Regulations Approved Document ADL1B provide a framework for identifying and capturing opportunities for significant, cost-effective improvements in the energy performance of *existing domestic buildings* when building work is undertaken (Office of the Deputy Prime Minister, 2006).
- It is expected that the demands and scope of the building regulations will be ramped up further through reduced CO_2 emissions targets in 2010.
- SAP is an evolving rating system with algorithms that may be adjusted and refined to account better for energy usage. It provides an alternative means up to and beyond 2010 for adjusting the impact of building regulations.
- As part of the compliance process, buildings will need to achieve an air permeability of better than 10 m^3/hm^2 at 50 Pa measured via pressure testing. This indicates the rate at which air leaks from a building envelope under a specified pressure and not only has direct energy implications, but can indicate construction quality and compliance in more general terms.

For these building regulations to be fully effective they should be embedded in an ongoing cycle of research and monitoring of new and existing buildings. Feedback should be provided to guide the process of technical innovation at all levels, to refine guidance on construction (Accredited Construction Details), and to underpin the development of SAP and future revisions of Part L. Joined-up research would help to place their compliance and effectiveness in the context of wider social, economic and environmental changes.

SAP AND EXISTING DATASETS

If SAP is central to the ongoing development of building regulations then it should be recalled that as an energy rating system defined on a non-linear scale of 1-100, its utility lies in delineating relative energy efficiency (in theory) for one building in comparison with another. Building regulations make use of its corresponding predictions for annual carbon emissions (kilograms CO_2 per annum). This is similar to carbon emission figures given for cars (grams CO_2 per kilometre) in order to compare and tax different models. Vehicle fuel consumption depends on real driving conditions, such as urban or rural, and driver behaviour. But unlike buildings, cars are mass-produced to tight specifications, so there is an important distinction for SAP: the figures for cars are still based on actual data measured on a track under standard conditions; whereas SAP is calculated using an energy balance model based on many assumptions and simplifications of building performance and operation (Building Research Establishment and Department of the Environment, Food and Rural Affairs, 2005) .

Fig. 1: Average stock SAP values vs. annual domestic gas consumption for LA areas in the UK. (Data sources =DTI, ONS)



Allowing for the impact of social and lifestyle differences of occupants, at a sufficiently large scale SAP would still be expected to correlate statistically with actual energy consumption. From Figure 1, it is interesting to note that when average SAP values for dwellings in each local authority area are plotted against their gas consumption, with each data point corresponding to around 60,000 dwellings, there is no evidence of a relationship. Such results underline the need for a better understanding of occupant lifestyle factors influencing energy consumption, as well as the physical data underpinning the description of the stock, such as refining the algorithms for hot water consumption or lighting.

Currently there are numerous interview surveys conducted that examine different aspects of household characteristics and lifestyle (Table 1). This equates to data being collected from more than 80,000 households annually and that in some form or another include basic dwelling descriptions such as accommodation type and age, tenure, number of rooms, number of bedrooms and central heating.

Table 1: Current UK household surveys conducted annually via interview questionnaire.

Name Date	Size (Hhlds.)	Owner	Comments
General Household Survey (GHS)	~10,000	DLGC[1]	Hhold description, characteristics
Survey of English Housing (SEH)	20,000	DLGC	Attitudes to Housing
English House condition survey (EHCS)	8,000	DLGC	Levels of Decency Building Survey
Expenditure and Food Survey (EFS)	7000	DWP[2]	Energy Expenditure, Appliances
Family Resources Survey (FRS)	24,000	DWP	Detailed household income
British Household Panel Survey	10,500 UK	ISER[3]	Energy Expenditure, Appliances

[1] Department of Local Government and Communites
[2] Department of Works and Pensions
[3] Institute for Social and Economic Research

Fundamental to SAP and other energy model calculations are the basic parameters of dwelling size, age and type, for example in estimating the area of external walls. The classifications of the latter two are illustrated for SAP2006 in Table 2. Building age is important since many of the specific building performance characteristics can be inferred as a consequence of the building regulations in force at that time.

Unfortunately the large-scale household surveys do not systematically employ this method of classification for dwellings; instead each has a different variation. For instance, in the general household survey (GHS), when a dwelling is classified as a house or bungalow there are only a further 3 sub-categories: detached, semi-detached, or *terrace/end-of-terrace*. But in terms of external wall area, an end-of-terrace is equivalent to a semi-detached dwelling. If on average in the UK there are 6-8 conjoint dwellings in a row of terraces, then the inclusion of end-of-terrace within the terrace category would mean a potential misclassification in SAP terms of 25-33% of all terraces.

Furthermore the dwelling age classifications in the GHS are as follows: before 1919, between 1919 and 1944, between 1945 and 1964, between 1965 and 1984, 1985 or later, don't know but after 1944. Thus the disjunction of age bands compared with SAP categories and the lack of classification post-1985 greatly reduces the possibility of analysing the relationship of building regulations (and by implication the prevailing building standards) over the last 20 years with the wealth of sociological information about the household, including appliance ownership.

Table 2: Classification system for dwelling type and age used in SAP2006.

Dwelling type[1]:	Dwelling Age bands[3]:
house	before 1900
Bungalow	1900-1929
Flat	1930-1949
maisonette	1950-1966
	1967-1975
And one of [2]***:***	1976-1982
Detached	1983-1990
semi-detached	1991-1995
mid-terrace	1996-2002
end-terrace	2003-2006
enclosed mid-terrace	
enclosed end-terrace	

[1] A house or bungalow has a completely exposed ground floor and a completely exposed roof. A flat or maisonette does not have both.
[2] These apply to house or bungalow. 'Enclosed' is typically applicable for 'back-to-back' terraces, so that for example an enclosed mid-terrace has an external wall on one side only (the front).
[3] Age bands post-1966 correspond with amendments in the building regulations, but generally one year after their introduction to allow for completion of dwellings approved under the previous regulations.

The Survey of English Housing has a similar system, but has a follow-up question to obtain exact years of dwelling construction for dwellings post-1985. The British Household Panel Survey (BHPS) that collects data on energy expenditure includes 'end-of-terrace' in its type classification, but entirely omits any question on dwelling age.

Another aspect that applies more generally is that in spite of the extensive number of surveys covering a diverse range of areas, none currently obtain direct data for energy usage or mandates to obtain energy billing data, except indirectly via its monthly cost in the EFS and the BHPS. The English House Condition Survey incorporates a detailed physical survey of the dwelling which is suitable for generating a simplified version of SAP, but is primarily concerned with levels of decency in housing, rather than energy usage. This remained the case even for the special 1996 version of the survey that incorporated more detailed energy performance related data and billing records for a sub-sample, and represents the last occasion that internal spot temperature measurements were made on a large scale for dwellings across England.

The potential of using these surveys to investigate social factors influencing carbon emissions associated with dwellings is severely compromised both in terms of the relationship with SAP rating and by the lack of data on actual energy usage or internal temperatures, even for a sub-sample of participants in these surveys. CaRB proposes to recommend ways to rationalise the dwelling classification so that they are at least compatible - a process that parallels the harmonisation already undertaken with social-demographic data of the occupants (Office for National Statistics, 2004).

CaRB BUILDING DATA REPOSITORY

CaRB is establishing a building data repository that would complement the Energy Data Centre at the UK Energy Research Centre (UKERC); indeed it may be located in a number of physical centres but accessed via a common interface. Such a data repository can:

- Provide a data dissemination service to the UK building research community, by either storing or linking to data located elsewhere.
- Establish secure data curation facilities, including supporting documentation, so as to ensure that data remains accessible over the long term.
- To add value to existing studies by converting datasets as far as possible into common database structures and classification systems that would permit far greater comparison and linking of results across datasets.

Table 3: Datasets currently being processed for data repository.

Name Date	Size, duration	Sample	Type	Comments
MK0 1989-91	150 1.5yr	Milton Keynes Energy Park	SAP, Energy, 29 with Temp.	Well-insulated, condensing boiler
MK1 2005-6	15 1.25yr	Milton Keynes Energy Park	SAP, Energy Temp., Socio.	Longitudinal Follow-up to MK0
Super Insulated 1994	14 1yr	Brixton	Energy, Temp.	5 controls
WarmFront 2004	3,108 14 days	National, 4 cities	SAP, Social, Energy, Temp.	Fuel poverty 1581 monitored data
Solar Crtyd 2005-6	3 1.25yr	Milton Keynes	SAP, Energy Temp., Socio.	Passive solar design
Bartlett Staff 2005	15 100 days	London	Temp.	Summer monitoring
Domestic Air-Con. 2005	7 100 days	London and South-East	Temp.	Summer monitoring
CO Study 2005	199 21 days	London	Temp.	Low socio-economic sample

Datasets immediately available for preparation for the repository are listed in Table 3. Simply in terms of internal temperature measurement, they amount to almost 60,000 dwelling days of hourly data and span 16 years. CaRB has begun a process of integrating or organising these datasets into a coherent structure for the domestic sector, both in the social and technical attributes of dwellings and of energy consumption. This will permit the development of more robust and generalised data structures that account for the varied and complex nature of the UK building stock, as well as harmonised or compatible classification systems. If this is accompanied by validated formats for questionnaires or building survey work then it is hoped that in future this would evolve into a recognised standard around which future studies could base their data collection and ultimately add to the repository.

SUMMARY

In the transformation to a low carbon economy, joined-up research should follow as the corollary of effective joined-up government. Part-L of the 2006 Building Regulations represents a strategic shift to a performance based approach with targets for overall CO_2 emissions, via a SAP calculation. With an expected revision to take place in 2010, the role of coordinated research and monitoring is emphasised to ensure regulatory effectiveness and compliance in both the new and existing stock.

Unfortunately, incompatible categorisation in major UK household surveys severely restricts their use in understanding the role of social and lifestyle factors on energy use in the building stock. CaRB recommends that dwelling classifications should be harmonised, to parallel what has already been achieved with socio-demographic data. Equally, if monitored energy data could be collected, even for a sub-sample from these studies, and either directly or via mandates for billing data, then this would also represent an important advance in the data available to improve SAP and energy models.

To facilitate joined-up research, CaRB is proposing the establishment of a building data repository that will initially include building, temperature and energy data available from existing projects. Considerable further work remains for these to be integrated into a compatible database structure and classification system, but ultimately these will form a generalised structure to be made available for use in future domestic building research.

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