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Carbon Reduction in Buildings (CaRB) - Understanding the Social and Technical Factors that Influence Energy Use in UK Homes

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Attempts to reduce the energy consumed in UK homes have met with limited success. One reason for this is a lack of understanding of how people interact with domestic technology – heating systems, lights, electrical equipment and so forth. Attaining such an understanding is hampered by a chronic shortage of detailed energy use data matched to descriptions of the house, the occupants, the internal conditions and the installed services and appliances. Without such information it is impossible to produce transparent and valid models for understanding and predicting energy use. The Carbon Reduction in Buildings (CaRB) consortium of five UK universities plans to develop socio-technical models of energy use, underpinned by a flow of data from a longitudinal monitoring campaign involving several hundred UK homes. This paper outlines the models proposed, the preliminary monitoring work and the structure of the proposed longitudinal study.

Keywords: carbon reduction, energy use, UK homes, social factors, technical factors, modelling and longitudinal monitoring.

INTRODUCTION

Buildings currently account for nearly half of the UK's CO_2 emissions, with domestic energy consumption accounting for about 20% of the total (ONS, 2004). Since 1990, despite tighter building regulations relating to the conservation of fuel and power (HMSO 2006), energy efficiency campaigns and subsidised energy conservation measures, CO_2 emissions for space and water heating have remained stubbornly level (see Figure 1).

Whilst the carbon emissions from lights and appliances has decreased since 1990 (see Figure 1) due to the change in the electricity generation mix, the delivered energy has risen. The underlying energy use for lighting, cooking and refrigeration (cold goods) remains high (see Figure 2), but there has been a marked increase in the energy consumed by so-called brown goods (TVs, VCRs, hi-fis) and by a range of other equipment (used for DIY, gardening and home offices).

Looking forwards, the trend is towards more, larger and more energy demanding, lights and appliances (DTI, 2003). Against this background, it is unlikely that the UK government's self-imposed target of a 20% reduction in CO_2 emissions by 2010 will be met. One of the reasons for the lack of success in curbing energy use in homes is our poor understanding of how people use energy in buildings, how they interact with new technology, and how they respond to socio-technical energy conservation initiatives. However, attaining such an understanding is hampered by a chronic shortage of openly available energy use data, matched with descriptions of physical form, occupancy characteristics, and installed appliances and services. Without such insights it is impossible to produce a transparent and validated strategy for modelling energy use in the nation's building stock which accounts for both the physical form of houses and the socio-technical factors which influence energy use.

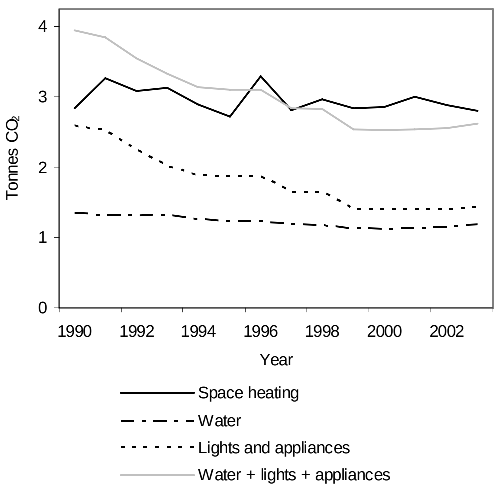

Fig. 1: Average UK household carbon dioxide emissions by end use type 1990 to 2003 (constructed from DTI 2005; ECI 2005).

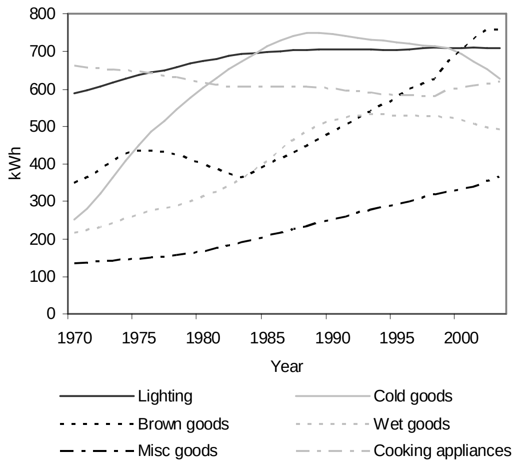

Fig. 2: Average UK household electricity use for lights and appliances 1970 to 2003 (constructed from DTI 2005; ECI 2005).

To address these issues, the Engineering and Physical Sciences Research Council (EPSRC) and the Carbon Trust have funded the four-year Carbon Reduction in Buildings (CaRB) consortium as part of their Carbon Visions programme. The consortium involves 18 staff at 5 universities and has two main aims:

1. To create a strategy for predicting the carbon emissions from domestic buildings that is applicable at the national, regional, city and community level, and which can forecast the impact of energy efficiency measures, the deployment of renewable energy technologies and the use of socio-technical interventions.

2. To conduct a longitudinal study of energy use in a large sample of buildings in order to develop and validate the model and to test promising socio-technical interventions.

The consortium's work is broad in scope, covering both domestic and non-domestic buildings and so cannot be fully explained in this paper. The discussion concentrates therefore on the work to be conducted in the domestic sector which requires an integrated approach by the multi-disciplinary CaRB team. Other recent papers have described some of the research into the non-domestic sector (Brown *et al* 2006; Altan and Ward 2006; and Bruhns *et al* 2006).

DOMESTIC ENERGY MODELLING

Two approaches to addressing the problem of modelling the socio-technical factors affecting energy use in homes are being explored – one is based on the development of enhanced occupancy models for use in BREDEM-based models and the other on a radically different approach - using Bayesian Belief Networks.

BREDEM Models

The BREDEM model (BRE, 2002) underpins domestic energy rating in the UK. It provides the basis for the Standard Assessment Procedure (SAP) (BRE, 2005) used to test the compliance of homes with Part L1 of the Building Regulations (HMSO (2006), which, in turn, provides the mechanism by which the UK can comply with the requirements of the forthcoming EU Energy Performance of Buildings (EPBD) (DIAG, 2006). The SAP provides the National Calculation Method for UK homes and overcomes weaknesses in socio-technical modelling by assuming a standard occupancy schedule. Other BREDEM variants allow different occupancies, but suitable data are rarely available so these too are usually used with the assumed standard occupancy. BREDEM underpins the BREHOMES calculation system which is used to predict the energy use of the entire UK stock of domestic buildings (Shorrock and Dunster, 1997) and it has also been used to model energy use from communities of homes (Gupta 2005; Rylatt *et al* 2003).

BREDEM programs predict the influence of location, geometry, construction and the heating system on space heating energy use. The algorithms for calculating hot water and lighting energy use are, however, based on simple relationships based on floor area and occupant numbers, and there is no attempt to predict energy use for individual appliances. The impact of home owners on the heating set point and the ventilation rates cannot be predicted and neither, therefore, can linked socio-technical phenomena. For example, the energy savings due to installing energy efficiency measures cannot reliably be determined because BREDEM models have no mechanism for predicting how much of the benefit will be taken as reduced energy consumption and how much as an increase in the internal temperature (so-called ‘take back’). This is a significant barrier to policy making given that in the average UK home, energy consumption for lights and appliances and the provision of hot water is comparable to that used for space heating (see Figure 1) and in new homes may actually be higher.

BAYESIAN BELIEF NETWORKS

In social, psychological and economic systems, the affect of one variable on another is complex or poorly understood and so, it is argued (Shipworth 2005), ‘normal’ statistical methods, such as regression, will fail to capture the complexities involved. For example, consider the proposition that the ‘education of head of household’ (independent variable) affects ‘home energy use’ (dependent variable). Whilst a direct relationship might be proposed, and indeed a statistical relationship devised, there are in fact a great many other factors which are influential (in direct and indirect ways) and, moreover, these factors are ‘interdependent’ and so interact with each other to create confounding effects. For example, ‘education is positively correlated with ‘income’; ‘income’ is positively correlated with ‘product ownership’ (a mediating variable); and ‘product ownership’ is positively correlated with ‘home energy use’. However, ‘education’ is positively correlated with ‘environmental awareness’, but ‘environmental awareness’ is *negatively* correlated with ‘home energy use’ for *some* energy user ‘market segments’ (a conditioning variable). Figure 3 illustrates how ‘education’ acts both to increase (via the dashed pathway) and decrease in come cases (via the dotted pathway), ‘home energy use’. These conflicting pathways (also called ‘frustrated’ pathways) help explain why some energy savings initiatives do not deliver the expected results – a phenomenon of ‘take-back’.

These complex interactions between variables are relatively easy to represent and model using Bayesian Belief Networks (BBNs). However, to build a functioning model, probabilities have to be added to the network as in Figure 4.

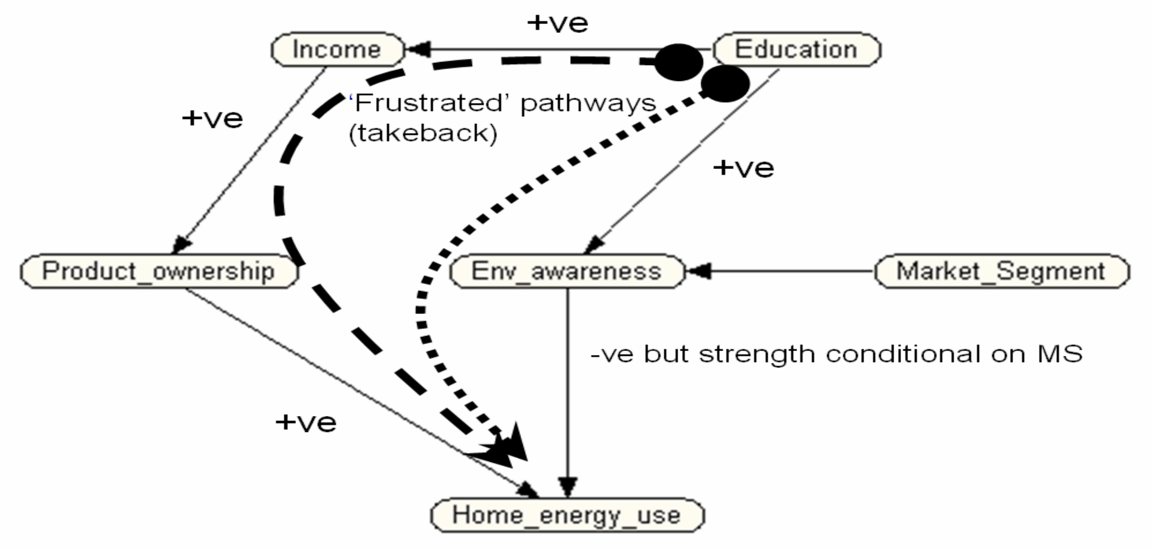

Fig. 3: An illustrative example of a Bayesian Belief Network showing the influences of 'Education' on 'Home energy use'. The dotted and dashed lines show 'frustrated' message pathways through the network.

Once built, the CaRB BBN model will allow estimations of the likely annual energy use (or carbon emissions) nationally, for a specific community, or for an individual home. The model will also show which variables, or combinations of variables, have the greatest impact on home energy use and the size of that impact. Policies and programmes can then be developed to target these variables.

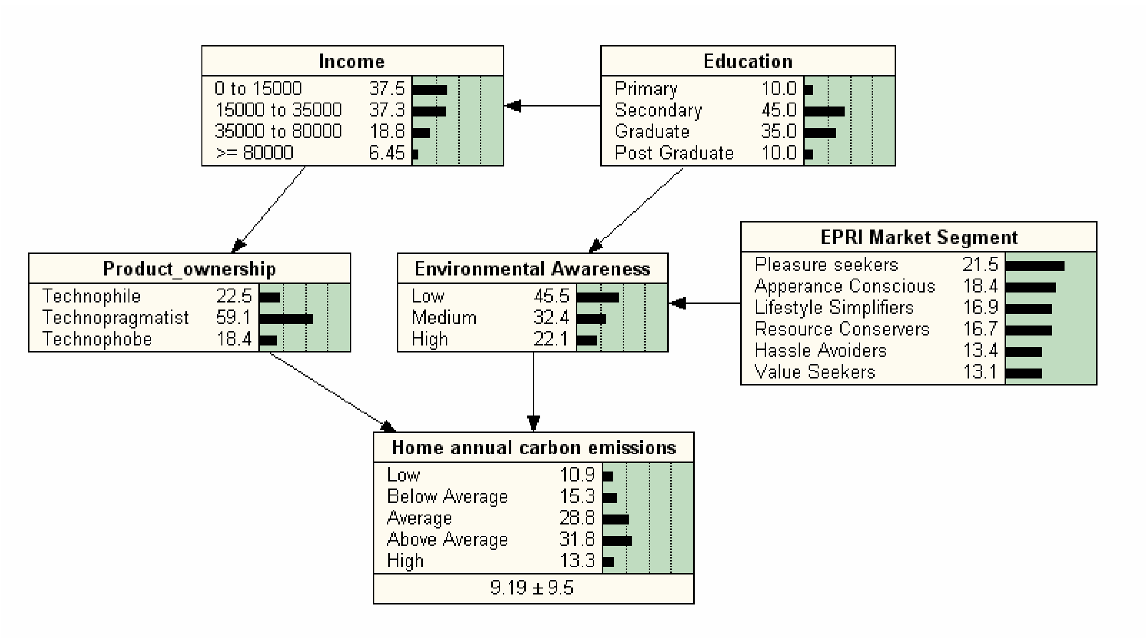

Fig. 4: The network with the addition of illustrative probability data.

DOMESTIC ENERGY MONITORING

Prior to embarking on a new longitudinal monitoring campaign, previous energy monitoring studies were reviewed. A Carbon Data Repository has been created in which data from a number of studies are archived in a standard format (Summerfield *et al*, 2006b). The repository currently contains descriptions of 43 UK projects (13 domestic and 22 non-domestic) that are included because: they provide raw data for use in the CaRB project (see the Milton Keynes Pilot study below); the information contained might contribute to the development of models, their validation, or the scaling of CaRB findings to a National or Regional level (eg census data giving household characteristics); or they might help in the development of the CaRB research methodology and in benchmarking the results (eg the English House Condition Surveys). Monitoring studies in which the CaRB team are directly involved are summarised in Table 1 and described below.

ECO'N' HOMES

The Eco'n'homes are being monitored for a year by Leicester City Council (LCC) as part of an EU project to assess the impact of technical interventions on energy use and associated carbon reductions. The package of technical interventions will be used in each home, such as improved insulation and/or a new gas boiler and controls. The 100 or so homes will be subject to a whole house energy survey, which involves a house visit by a trained surveyor to record the house geometry and the construction and heating systems, such that a National Home Energy Rating (NHER) (and the SAP value), can be obtained. The weekly electricity and gas usage will be collected by LCC staff by telephoning the home owners for their meter readings.

The study is of interest to CaRB as it enables the impact of technical interventions in poor quality inner-city homes to be evaluated. The CaRB team will enhance the monitoring effort by measuring internal temperatures to understand the impact of the energy efficiency measures on these. Using the CaRB questionnaire, appliance ownership and usage in the properties will be recorded to provide additional data for the development of BREDEM occupancy models and to test the BBN models.

EST HOT WATER STUDY

The Energy Saving Trust has initiated a study in 120 homes nationwide, monitoring the hot water supplied from the storage tank to determine the total usage of hot water and the way this varies in time. In a sub-set of around 24 homes, the end use of the water (bath, hand basin, washing machine, etc) will also be monitored. The quarterly electricity and gas use will be recorded by the project team, with monthly readings provided by the householder.

The CaRB team will supplement the study by distributing the CaRB questionnaire and by recording internal temperatures. The study is particularly useful for the CaRB team as it may provide the only data which permit the disaggregation of energy use for water heating from that used for space heating, gas fires and gas cooking.

THE MILTON KEYNES PILOT

Although a longitudinal study can be set up within the life-time of the CaRB project, it is unlikely that trends in energy use will be able to be observed; yet it is desirable to gain insight into the information which is likely to emerge. Therefore CaRB has sought suitable prior studies with accessible temperature, energy, and socio-technical data. One such study was conducted in the Milton Keynes Energy Park, where 160 low energy homes (with condensing boilers and higher levels of insulation than were standard at the time) had hourly energy data collected between 1989 and 1991. A sub-sample of 29 dwellings also supplied hourly monitored temperatures in three rooms, and a social and behavioural survey of the occupants was also conducted (Edwards, 1990). Of these, 15 dwellings were recruited for the CaRB follow-up survey, which involved ongoing energy, temperature and relative humidity monitoring, as well as a detailed social survey.

Table 1: Ongoing and planned domestic energy monitoring studies in the CaRB project.

<table>
<tr><th rowspan="2">Study</th><th rowspan="2">Number of Homes</th><th rowspan="2">Duration per Home</th><th rowspan="2">Location</th><th rowspan="2">Operator</th><th colspan="2">Questionnaires</th><th colspan="3">Monitoring</th><th colspan="2">Surveys</th></tr>
<tr><th>Occupants and Appliances</th><th>Interview</th><th>Electricity and Gas</th><th>Appliances</th><th>Internal Temperatures</th><th>House Survey</th><th>Appliances</th></tr>
<tr><td colspan="12">Preliminary Studies</td></tr>
<tr><td>Eco'n' Homes</td><td>75 - 100</td><td>1yr</td><td>North Leic</td><td>Leic City Council</td><td>CaRB Question-naire</td><td>No</td><td>Weekly by occupier</td><td>No</td><td>Yes</td><td>NHER</td><td>No</td></tr>
<tr><td>EST Hot Water</td><td>120</td><td>1yr</td><td>UK clusters</td><td>EST/ BSRIA</td><td>CaRB Question-naire</td><td>No</td><td>Monthly by occupier
Quarterly by researchers</td><td>No</td><td>Yes</td><td>For EST purposes</td><td>No</td></tr>
<tr><td>Milton Keynes Pilot</td><td>15</td><td>1yr</td><td>Milton Keynes</td><td>CaRB</td><td>Interview
Question-naire</td><td>Yes</td><td>Monthly by researcher</td><td>No</td><td>Yes</td><td>Original BREDEM Survey</td><td>No</td></tr>
<tr><td colspan="12">Longitudinal Study</td></tr>
<tr><td>1 CaRB Baseline</td><td>500 – 1000[a]</td><td>1 yr</td><td>CaRB clusters</td><td rowspan="5">CaRB</td><td rowspan="5">CaRB Question-naire</td><td>No</td><td>Monthly by occupier</td><td>No</td><td>No</td><td rowspan="5">NHER with CaRB additions</td><td rowspan="5">Yes</td></tr>
<tr><td>2 CaRB Detailed Monitoring</td><td>50</td><td>2wks to 1yr[b]</td><td>From within CaRB clusters[c]</td><td>No</td><td rowspan="2">Logged
5 min elec
30 min gas[d]</td><td>Yes[e]</td><td>Yes</td></tr>
<tr><td>3 CaRB In-depth Interviews</td><td>50</td><td>2hrs</td><td>Various</td><td>Yes[f]</td><td>No</td><td>No</td></tr>
<tr><td>4 CaRB Longitudinal</td><td>300[g]</td><td>2+ yrs</td><td>CaRB clusters</td><td>No</td><td rowspan="2">Logged
30 min[h]</td><td>No</td><td>Yes</td></tr>
<tr><td>5 CaRB Diagnostics</td><td>See No[i]</td><td>2wks to 1yr</td><td>From within CaRB clusters</td><td>No</td><td>Yes[e]</td><td>Yes</td></tr>
</table>

(a) Depends on response rate to questionnaire survey.
(b) One year for small number of homes to establish seasonal variation for some usages, eg tumble dryer.
(c) Some interviews also conducted in homes outside the cluster.
(d) As required to provide insight into practices.
(e) For larger fixed appliances in regular use and where feasible, monitoring at socket. Appliances 'always on' would be monitored on site for a short period to establish constant load. Usage inferred using novel techniques such as temperature logging of lighting and shower rooms.
(f) Interview about practices regarding lighting and 'infotainment' (use of TV, audio, home computers etc). Link to energy data if available from other studies on same home.
(g) Number depends on households willing to participate and monitoring resources, will change as households move house.
(h) Automated logging preferred, otherwise monthly via occupier.
(i) Number dictated by the need to explain changes in energy use.

The study has provided invaluable experience in monitoring and survey techniques and an appreciation for the role of coherent database structures to maintain the long-term value and accessibility of the data. The results thus far indicate that under standardised winter conditions, energy consumption per house has increased but even more so the energy use per person. Over 15 years here has been a 15-25% per person increase in gas consumption and a 20-30% per person electricity increase, while internal temperatures have remained largely unchanged - with even a drop recorded for bedroom temperature (Summerfield *et al*, 2006a). This may be due to a combination of fabric or boiler efficiency decline through lack of maintenance and/or behavioural changes leading to increased ventilation rates, for example, leaving bedroom windows open during midwinter. The results highlight the dynamic nature of buildings even within this cohort, and the potential complex interaction of socio-technical influences on energy use.

THE CARB LONGITUDINAL STUDY

OBJECTIVES

Establishing a longitudinal study of energy use in homes is one of the aims of the CaRB Project. Longitudinal studies have been common in many areas of science, in particular epidemiology and health sciences where considerable academic literature and specific methodologies have been developed to assist with appropriate targeting and timing of policy initiatives. This has been reviewed in order to understand how best to undertake the CaRB study (Summerfield *et al*, 2005). The longitudinal study provides the flow of data necessary to ground the socio-technical energy models; much as meteorologists need data to anchor climate models to reality. This would be a powerful tool for predicting the likely evolution of energy use and CO_2 emissions.

The study requires the collection of whole house energy consumption data in a manner that can be sustained over a prolonged period of time in order to quantify trends due to both intrinsic factors (such as socio-economic changes in the household, changes in the ownership and usage of appliances, or energy efficiency measures) and extrinsic factors (such as rising fuel prices or energy awareness campaigns) - such factors can be seen as natural interventions. The current energy use, and data about the socio-economic make up of each household, appliance usage and the physical form and construction of the house, provide the baseline data against which changes can be charted. The collection of such data requires the distribution of a rather extensive questionnaire and a home energy survey. The questionnaire data can be used to build the links and probability tables in the BBN, but a high questionnaire return rate is needed of in order to minimise non-response bias. This requirement sets the minimum sample size and strongly influences the structuring of the study.

The cohort of homes recruited for the longitudinal study can also be used for more intensive monitoring (of the usage and consequential energy demands of individual lights and appliances) to validate the enhanced BREDEM-type models and to provide a stimulus for the in-depth interviews about energy consumption practices. Such interviews will seek to understand the personal, social and technical factors which impact on lighting, washing, ‘info-tainment’ (TV, video, DVD, home computing, etc) and thermal comfort ‘practices’ (see for example, Stokes *et al*, 2006). These practices have been chosen because they are either high energy consumers or because the energy associated with them is rising rapidly (see Figure 2).

One of the challenges with any longitudinal monitoring study is to predict what parameters should be measured. For example, conservatories are often now heated and some are air conditioned, but 30 years ago this was not the case. A monitoring campaign begun then might not have recorded conservatory temperatures and could not have monitored the heating and cooling appliances within them. To pick up new trends in energy use as soon as possible, the CaRB team plans to undertake diagnostic monitoring; that is, additional investigations to explain observed changes in energy demand that cannot be attributed to climatic variations.

The work is set against a backdrop of rapid developments in non-invasive, small, low cost logging systems which can be used to record temperature, humidity, and energy use at sockets or from utility meters. In some systems this can be relayed wirelessly to a logger and subsequently relayed to the CaRB team's computer, using GSM mobile phone technology or internet protocol via broadband. Such systems are under constant review by the CaRB team.

STRUCTURE OF THE STUDY

It is evident from the foregoing that the requirements of the CaRB data collection could place an onerous burden on the householders, at least initially when the baseline data are being collected, and this needs to be carefully managed. The study must also be affordable, safe (for the field workers) and manageable with the project's resources. The study must also be organised so that the ongoing data collection and storage processes can continue to operate in a reliable and cost-effective manner when the CaRB project ends. These and other factors (see below) led to the decision to use a university-based, distributed clusters approach, in which the houses studied would be occupied by employees at each of the 5 CaRB partner universities. A similar 5 component process (see Table 1) will be followed successively at each university.

Firstly, a random sample of approximately 200 homes will be selected from the employee list of a university. The aim here is to establish a contact person for the household, to whom the questionnaire can be sent. Permission to conduct a house survey will be sought, along with a commitment to provide monthly meter readings. A request for past energy bills and a signed mandate allowing the CaRB team to access energy billing data will also be made. Other methods of collecting the whole house energy data are currently being explored. A whole house energy survey will be conducted by a trained home energy assessor, meter readings will be taken and a complete inventory of appliances and lights will be created. Temperature loggers will be installed in as many homes as possible. It is hoped that the questionnaire, energy data and survey will be obtained for at least 50% of the households sampled. These data provide the baseline description for each household.

Secondly, a smaller sample of about 10 homes will be selected, in which detail monitoring will be conducted in order to build up a picture of the usage and energy consumption of individual lights and appliances. This will help in the interpretation of the whole house energy use data.

Thirdly, the homes subject to the detailed monitoring will also become a target for the in depth interviews which seek to understand the energy using practices and the motivations for them.

Fourthly, each household in the longitudinal cohort will be contacted periodically to ascertain if there have been socio-economic or technical (equipment or energy efficiency) developments. The gas and electricity use will be monitored automatically if possible, but failing this the household contact person will be asked to provide, bi-annually, another set of monthly meter readings – in other words, longitudinal data. Finally, the diagnostic monitoring will be initiated as and when necessary to investigate the causes of observed changes in energy use.

Investigations will be initiated, as necessary, to try and understand any significant changes in energy use or patterns of use. However, this must be done cautiously so that the study does not begin to influence energy consuming behaviours.

ADVANTAGES OF THE CHOSEN STRUCTURE

The use of clusters of homes in which university employees live offers a number of practical advantages: the likelihood of a achieving a high response rate is improved (the home owner works for the research organisation) and can be easily contacted; the geographical proximity of homes to the 'hub' university mean that travel costs to make home visits are reduced; clustering makes the home energy surveys less expensive (the surveyors can schedule a number of surveys in one day) and the same weather data are applicable to many homes; there is less risk to the safety for researchers as they will be visiting the homes of individuals from the same place of work (though probably not known to them); and the likelihood of equipment loss is reduced. As the home contact will frequently visit the university, it also becomes possible to: use the internal post (and email) to resolve problems; for meetings to be set up to assist with filling in questionnaires (and to contemplate the electronic completion of questionnaires); and for information to be exchanged (for example, old energy bills), or data loggers, sensors and so forth. The structure also means that there is the prospect of incrementally refining the methodology as successive cohorts are recruited by each of the CaRB universities and, in the future, extending the study by enjoining other universities.

Whilst having these benefits, the clusters of homes will still be geographically distributed and cover a range of ethnic and socio-economic groups (for example, 56% of the 2400 full-time staff at De Montfort University are non-academic and over 30% are not white British). However, some groups with characteristics that influence energy use will not be sampled; in particular those without at least one member in work, and households composed entirely of retired individuals. However, once the characteristics of the university cohorts are known, under-represented groups can be identified and steps taken to 'fill the gaps'.

With the average time spent in a UK house being about 8 years (ONS 2004), natural 'churn' within the study group is inevitable. However, since the house contact is a university employee, it will be evident when the household has moved home. Then a new contact in the original house can be contacted and/or the household can be 'followed' to the new house. Such movements can be seen as rather useful: it becomes possible to explore how energy use is affected if a different family lives in one of the cluster houses, or how energy use changes if a known household moves to a new house. The issue of whether to track families or houses is, however, still an open question for the CaRB team, although buildings are certainly easier to keep track of than people.

CONCLUSIONS

The use of energy in UK homes for lighting and electrical equipment is increasing and can exceed that used for space heating. A lack of understanding about the interaction of social and technical factors means that conventional domestic energy models cannot reliably predict current and likely future domestic energy demands. The Carbon Reduction in Buildings (CaRB) consortium seeks to develop this understanding and thus to build new transparent models. The work will be underpinned by a longitudinal monitoring campaign, which will track the evolution of domestic energy consumption over time and enable the socio-technical factors influencing this usage to be explained.

ACKNOWLEDGEMENTS

This work forms part of the work of the Carbon Reduction in Buildings (CaRB) Consortium. CaRB has five UK partners: De Montfort University, University College London, the University of Reading, the University of Manchester and the University of Sheffield. CaRB is supported by the Carbon Vision initiative which is jointly funded by the Carbon Trust and the Engineering and Physical Sciences Research Council, with additional support from the Economic and Social Research Council and the Natural Environment Research Council. The partners are assisted by a steering panel of representatives from UK industry and government. See http://www.carb.org.uk for further details.

REFERENCES

Altan H and Ward I (2006), "Non-domestic energy use – experiences of the higher education sector". Paper pending COBRA 2006 Conference, 7-8 Sept, London.

BRE (2002), "BREDEM-8 model description 2001 update", Anderson, Chapman, Cutland, Dickson, Doran, Henderson, Iles, Kosmina and Shorrock, Building Research Establishment publications.

Brown N, Wright AJ, Caeiro AJ, Altan H and Summerfield AJ (2006), "Large scale energy surveys in the UK retail sector". Paper pending COBRA 2006 Conference, 7-8 Sept, London, UK.

Bruhns H, Steadman P and Marjanovic L (2006), "A preliminary model of non-domestic energy use for England and Wales". Paper pending COBRA 2006 Conference, 7-8 Sept, London.

DTI (2002), "Our energy future – creating a low carbon economy", UK Government White Paper, Department of Trade and Industry publication.

DTI (2003), "Energy consumption in the United Kingdom", Department of Trade and Industry publication.

Edwards J (1990), "Low energy dwellings in the Milton Keynes Energy Park", *Energy Management*, 26, 32-33.

Gupta R (2005), "Investigating the potential for local carbon emission reductions: developing a GIS based domestic energy. Carbon-counting and Carbon-reduction Model (DECoRuM)". Proceedings of Solar World Congress, 6-12 Aug, Orlando, Florida.

ONS (2004), "The impact of UK households on the environment", Economic Trends 611, October, Office for National Statistics.

Rylatt M, Gadsden S and Lomas K (2003), "Using GIS to estimate the replacement potential of solar energy for urban dwellings", *Environment and Planning B, Planning and Design*, 30, 51-68.

Shipworth D (2005), "Synergies and conflicts on the landscape of domestic energy consumption: beyond metaphor". Proceedings of the 7th European Council for an Energy Efficient Economy Summer Study, 30 May – 4 June, Mandelieu, France.

Shorrock LD and Dunster JE (1997), “The physically based model BREHOMES and its use in deriving scenarios for the energy use and carbon dioxide emissions of the UK housing stock”, *Energy Policy*, 25(12), 1027–1037.

Stokes M, Crosbie T and Guy S (2006), “Shedding light on domestic energy use: a cross-discipline study of lighting homes”. Paper pending COBRA 2006 Conference, 7-8 Sept, London.

Summerfield AJ, Bruhns HR, Caeiro J, Steadman JP and Oreszczyn T (2005), “Life course building epidemiology: an alternative approach to the collection and analysis of carbon emission data”. Proceedings of RICS COBRA 2005 Conference, 4-8 July, Queensland University of Technology, Brisbane, Australia.

Summerfield AJ, Bruhns HR, Caeiro JA, Steadman JP and Oreszczyn T (2006a), “Milton Keynes Energy Park revisited: changes in internal temperatures”. Proceedings of Comfort and Energy Use in Buildings: Getting them Right, Network for Energy and Comfort in Buildings, 27-30 April, Windsor, UK.

Summerfield AJ, Lowe RJ, Firth SK, Wall R and Oreszczyn T (2006b), “Carbon emissions and the case for joined-up research: adding value to household building energy datasets”. Paper pending COBRA 2006 Conference, 7-8 Sept, London.

WEBSITE REFERENCES

BRE (2005), “SAP 2005 Specification”, http://projects.bre.co.uk/sap2005/

DIAG (2006), “Energy performance of buildings directive implementation advisory group”, http://www.diag.org.uk/

DTI (2005), “Energy consumption in the United Kingdom”, Department of Trade and Industry, DTI/Pub 1.5k/7/02/AR. URN 02/1049, http://www.dti.gov.uk/energy/statistics/publications/energy-consumption/page17658.html

ECI (2005), “DECADE: Domestic equipment and carbon dioxide emissions”, Second Year Report, Environmental Change Institute, University of Oxford, http://www.eci.ox.ac.uk/lowercf/decade.html

HMSO (2006), “Approved Document L1A, Conservation of fuel and power in dwellings”, 2006 Edition, http://www.dclg.gov.uk/

OTHER USEFUL WEBSITES

www.bre.co.uk

www.carb.org

www.carbontrust.co.uk/technology/carbonvision/

www.dti.gov.uk

http://www.nher.co.uk/