Modelling approaches for retrofitting energy systems in cities: current practice and future challenges in Newcastle upon Tyne

Abstract

This paper proposes the initial formulation of an activity-based model framework to model and quantify the effects of household practices on energy demand in the domestic sector. Indeed, this socio-technical research is seeking to understand the effects of two salient aspects of the interaction between energy consumption and household practices in a scenario of imposed retrofitted: 1) take back effect; and 2) demand-side management. A conceptual framework and a detailed case study of 200 social sector households in Newcastle upon Tyne are proposed to bring together both the theory and practice.

The paper reviews the UK low carbon agenda to provide an overview of the key policies for carbon reduction in the domestic sector involving retrofit insulation. It, then, briefly examines the take back effect and demand side management concepts to contextualise the emphasis of the proposed study. Further, it looks at practice theory for connecting socio-technical systems and reviews the urban energy modelling to simulate and quantify the interplay between technical and social systems (take back effect and demand side management). Furthermore, practices and modelling challenges at the local level are reviewed. Finally the case study is presented.

1. Introduction

The UK low carbon transition plan has set stringent national carbon reduction targets by 2050 (i.e. an 80% reduction in GHG emissions by 2050, against the 1990 baseline). The residential sector plays an important role in achieving this target. Households in the UK account for 27% of total carbon dioxide emissions (HM Government, 2006 as cited in Druckman and Jackson (2008)). Thus far, retrofitting energy efficiency interventions in houses have been intended to contribute to the reduction of current energy demands and improve the efficiency of the energy supply (Jennings, 2013).

Additionally, there is a growing body of academic research on governance, social and behavioural practices in households to describe and contextualise domestic dwelling practices with regard to usage of energy (Kane *et al.*, 2011). However, the interplay between energy consumption and household practices (e.g. daily activities such as cooking, having a shower and so on) in an imposed retrofitted scenario has not been as widely explored and, to the best of our knowledge, has not been modelled and/or quantified on the dwelling scale (down to the heater being switched on and off).

This paper proposes an activity-based model framework to model and quantify two salient aspects of the interaction between household practices and energy comsumption: 1) the take back effect; and 2) demand-side management. In this research household practices are called - 'energy activities', which originates from the practice theory and activity based modelling framework to understand and simulate energy usage in habitual actions within the home (e.g. cooking, laundry). To date, the practice research in the energy context has been largely qualitative.

Demand side management is understood to be the effort required to achieve flexible energy consumption (balancing the grid, days and time of electricity use, flexible domestic scenarios 'what if'). The take back effect is understood as less energy saving than expected which may not deliver the desired energy reduction. Energy saving and demand side management are quantifiable and are appropriate for incorporation in energy models.

The paper first reviews the UK carbon reduction agenda and local policies, then briefly examines the take back effect and demand side management concepts to contextualise the emphasis of the proposed study. Further, it considers practice theory in terms of connecting to a social technical system and then focuses on urban energy modelling, particularly in an activity-based model. Finally, the detailed implementation of the modelling approach in a case study of 200 social sector (retrofitted and non-retrofitted dwellings) households in Newcastle upon Tyne is described.

2. Background

2.1 Low carbon agenda

The UK Government is seeking to achieve its target of reducing the greenhouse gas emissions by 80% by 2050 against the 1990 baseline, by focusing on retrofit insulation of existing buildings. Retrofit insulation[1] is intended to contribute to the

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[1] This paper will use the definition of retrofitting insulation by Jennings (2013) who described retrofit as – "*...referring to planned improvements to existing buildings by means of altering, replacing or removing an existing technology or technologies …"* (Jennings, 2013, p. 59).

reduction in current energy demands and improving the efficiency of the energy supply (Jennings, 2013). Depending on the retrofit building-scale, benefits may range from "individual demand-side measures" to "centralized supply-side technologies" (Jennings, 2013, p. 60). For instance, the retrofit benefits for demand side measures may include decreased heating requirements as a result of upgrading external insulation. In addition, renewable technologies such as wind or solar photovoltaic (PV) may generate benefits in the supply side technologies.

A wide range of policies in the domestic sector have been designed to support the strategy for low carbon housing, mobilising financial resources from energy suppliers and electricity generators for retrofitting programmes. Energy efficiency policy has been very dynamic. This paper is analysing four schemes which have been launched since 2008 to date, in order to offer an overview of current domestic energy policy. The Carbon Emissions Reduction Target (CERT), the Community Energy Savings Programme (CESP), Energy Companies Obligations (ECO) and Green Deal are reviewed and discussed.

CERT and CESP were key schemes to achieve CO2 reduction in the domestic sector until 2012 and imposed savings obligations on energy suppliers and electricity generators (Ofgem, 2013a; Ofgem, 2013b). Different energy efficiency measures were delivered via partnerships between local authorities (including housing associations), delivery agents, supermarkets, other retailers and end users (Rosenow, 2012).

On the one hand, CERT aimed at reducing 293 Mtof CO2[2] (lifetime) between 2008 and 2012, with at least 40% of the target focused on priority group customers[3] (Ofgem, 2013a). A target of 296.9 Mt CO2 of carbon savings, equivalent to 101.3% was achieved[4] (ibid). Throughout CERT's five years of existence, 510MM measures[5] were installed and 2/3 of carbon saving come from insulation, whilst lighting measures contributed 17,3% to the carbon savings target (ibid). Furthermore, a legislative change removed compact fluorescent lamps from CERT in 2011, placing greater emphasis on other measures (ibid).

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[2] Mt= million tonnes of Carbon dioxide.

[3] Low income customers or over 70 years of age.

[4] The individual energy company target was not met, because two of them did not achieve it (Ofgem, 2013b).

[5] Measures are referred to insulation, Insulation obligation, lighting, heating, microgeneration & CHP, behavioural, demonstration actions and appliances (Ofgem, 2013b, p.10).

On the other hand, CESP focused on achieving an overall target of 19.25 Mt of CO_2 between 2009 and 2012[6], in specific low incomes areas (Ofgem, 2013b). Under CESP, 85% of the target was achieved (16.31 Mt CO_2) and 293,922 energy efficient measures[7] were installed, including 75,000 external solid wall insulation and 43,000 boilers (ibid). CESP was succeeded by the Energy Companies Obligations (ECO) (ibid), which was launched in 2013.

ECO focuses on low income residents, particularly in three areas: the Carbon emissions reduction obligation, the Carbon saving community and the Affordable warmth obligation (DECC, 2012). The overall carbon target for ECO set between 2013 and 2015 is 27.8 Mt CO_2 (ibid). The Carbon emissions reduction obligation targets reducing 20.9 Mt of CO_2 with a focus on hard-to-treat homes whilst the Carbon saving community target is 6.8 Mt of CO_2 focusing on the lowest 15% of the UK's most deprived areas (ibid). The Affordable warmth obligation is aimed at achieving a reduction in lifetime heating costs of £4.2bn (ibid).

ECO can be seen as the continuation of previous mechanisms (Rosenow and Eyre, 2012), whilst Green Deal is a market led framework. From 2013 and, until 2020, it is expected that this scheme will contribute to moving responsibility onto homeowners with regard to making energy efficiency improvements in their homes. Financial incentives such as no upfront costs and the possibility of reducing energy bills are expected to be attractive to consumers (DECC, 2013).

Energy efficient measures funded by the Green Deal will be collected by the electricity provider in installments, attached to the electricity bills (DECC, 2013). In addition, the 'Golden Rule', proposes that estimated savings must be greater than repayments (DECC, 2011). ECO and Green Deal are different schemes, however they can be linked using a brokerage mechanism which allows providers to access ECO funding from the energy companies (DECC, 2012).

With regard to the local area, in 2010, Newcastle City Council (NCC) signed the "EU Covenant of Mayors" which committed the council to developing a Sustainable Energy Action Plan (SEAP) to reduce carbon emissions by 20% by 2020 from its 2005 baseline (Newcastle City Council, 2010). This was followed by the Climate Change Strategy[8], launched in 2010, which included 'the domestic housing work stream', and involved different energy-related initiatives, such as existing

[6] 1 October 2009 to 31 December 2012.
[7] External solid wall insulation (26%), heating controls with a new heating system (20%) and boiler replacements (15%)
[8] "Citywide climate change strategy & action plan 2010 - 2020" (Newcastle City Council, 2010).

infrastructure retrofitting schemes (Davoudi and Brooks, 2012) and various programmes aimed at the residential sector (Newcastle City Council, 2010). In addition a Carbon Routemap strategy has been developed which includes future retrofitting projects (ibid).

The schemes reviewed in previous paragraphs have contributed and impacted on different areas. In terms of social perspectives, CERT and CESP had specific targets which were focused on low income areas; i.e. 40% of the CERT target was aimed at priority group customers and CESP was focused on achieving this target in specific low income areas (Ofgem, 2013a; Ofgem, 2013b). Furthermore, ECO targets are aimed at low income residents, focusing particularly on the lowest 15% of the UK's most deprived areas (DECC, 2012). As a result, in terms of retrofitting insulation, many existing buildings in low income areas have had improvements intended to contribute to the reduction of current energy demands and fuel poverty.

However, these schemes have not necessarily decreased the number of households living in fuel poverty (DECC, 2011 as cited in Rosenow, 2012) or it cannot be taken for granted that a reduction of energy consumption will occur (see Take back effect in section 2.2). Particularly high levels of fuel poverty can be explained because of increased energy prices (Rosenow, 2012). One of the factors that may contribute to increased energy bills is the cost of schemes. For example, Rosenow (2012) evidenced that the cost of the CERT programme, was passed on consumers, and at the average bill cost increased over £50 per year (ibid). Likewise, at the time of this paper there is an ongoing discussion about how the cost of ECO are being spread across all energy bills (See for example Consultation response from the Mayor of London (2014))

In terms of the economic impact, there are concerns about the transition from low cost to higher cost measures. Funding will be needed to achieve this transition, for example for cavity and loft insulation or low cost measures for solid wall insulation in hard-to-treat properties. To date mainstream retrofitting programmes have focused on "easy-to-treat" insulation. More than 45.000 households, for instance, have been retrofitted with cavity and loft insulation in Newcastle upon Tyne (Keirstead and Calderon, 2012) and 17% of CERT measures have focused on lighting (Ofgem, 2013a).

As Rosenow and Eyre (2012) argued, if recent rates of installation are maintained, low cost options will decline over the next few years. Then, "higher cost effective" measures will need to be included. There are also other economic impacts to take into account such as the effect of Green Deal on the housing market or an increase in debt levels in the financial sector (since homeowners will have a long term loan attached to their properties), however these are not going to be reviewed in this document because, at this point the effect of Green Deal on consumers is still unknown.

2.2 Take back effect

This effect can be understood as less energy saving than expected, as a result of improvements in energy efficiency measures. The effect known variously as - *'rebound'* , *'take back'*, *'comfort factor' or 'foregone savings'* (Sanders and Phillipson, 2006) has become increasingly important in energy research and in the evaluation of the low carbon agenda. Indeed, retrofit potential remains to be seen, since the 'take back effect' has to be considered in terms of the estimation of energy consumption.

Interestingly, awareness of the 'rebound effect' appears not to be new. In the 19th century, the economist W.S. Jevons predicted steam engine improvements (technology), bringing about the saving of coal (energy), would lead to higher consumption – *"less fuel consumption per unit of equipment causes greater total consumption"* (Alcott *et al.*, 2012, p. 7). 'Jevons Paradox' has been used as an analogy to explain the extra energy consumption in the domestic sector as a result of energy efficiency measures (Vale and Vale, 2010).

Previous studies have shown the difference between actual saving measures and predicted consumption (Sanders and Phillipson, 2006; Vale and Vale, 2010). For example, after an assessment of more than 500 studies and reports, the UK Energy Research Centre concluded that estimation of energy saving has failed to take into account the 'take back effect' (Sorrell, 2007).

Principally, this effect has largely been explained in terms of the 'comfort factor', however it is not the only element contributing to the shortfall in energy saving (Milne and Boardman, 2000). Indeed, Sanders and Phillipson (2006) proposed the following terminology to be used when analyzing diverse studies which consider the difference between actual and predicted energy saving following installation of better insulation:

$$\text{Reduction factor (RF)} = \text{Comfort factor (CF)} + \text{Other factor (OF)} \qquad (1)$$

Where *RF* is – *"the amount by which the measured energy saving following refurbishment is less than the saving predicted from theory"* (Sanders and Phillipson, 2006, page 2?). CF is – *"the part of the reduction factor which can be* *identified as being caused through improved internal temperatures*" (ibid) and OF is – "*the part of the reduction factor which is not explained by the comfort factor but includes other benefits taken by the householders*" (ibid). The magnitude of the reduction factor and, specifically, the comfort factor varies dependant on which of the different studies is considered (See for example; Shorrock *et al.*, 2005; Sorrell, 2007). Indeed, Sander and Phillipson (2006) suggested a 50% of RF, of which 15% is the comfort factor.

2.3 Demand side management

In the past, the energy supply response was often assumed to take a passive form (Guy *et al.*, 2001). In the electricity context, utility providers met increased demand through 'supply oriented options' (ibid). However, nowadays demand side management (DSM) is recognized as offering new opportunities for promoting network member interactions 'beyond-the-meter'. Most importantly, DSM presents the ability to transform the end-user from passive user into active consumer (ibid). In the UK, the Green Deal programme (introduced through the 2011 Energy Act) and the introduction of smart metering have offered new opportunities for improving energy efficiency and demand side responses (IEA, 2011).

Indeed, it is expected that once gas and electricity meters are replaced, the improvement in terms of use of time and variable tariffs will be significant (ibid). Therefore, it is argued in this paper that 'demand side flexibility' plays an important role in DSM, offering the potential to integrate urban energy system models, since practices may eventually be modified and will engage end users in activities/routines which can allow for a reduction in their energy consumption.

3. Household practices and energy demand.

Domestic energy use approaches have moved from a statement of technological determinism to a socio-cultural approach. As Higginson *et al.* (2011) emphasized, three main approaches can be distinguished according to the location of the agency; technological, individualist and socio-cultural perspectives. The emphasis is placed on the technology, individual or society and culture respectively (ibid). For example, a desired energy saving outcome can be achieved with energy efficient technology (technology determinism approach), information, education, price incentives (individual approach) or policies, social marketing or the involvement of local communities (social and cultural approach) (ibid). For a more in-depth review of these positions, see Higginson *et al.* (2011).

A socio-technical approach, therefore, enables the incorporation of these three perspectives to understand energy use (Wilhite et al., 2000; Shove, 2003b; Higginson *et al*., 2011). Practice theory is a framework which allows for the connection of different perspectives within the socio-technical systems approaches. This theory reformulates the relationship between individuals and society and enables the understanding of how the social system can be observed throughrecursive practices reproduced by agents. It then locates social practices as the core of the theory.

In the past, social theory had been seen as an individual-society dualism (Giddens and Pierson, 1998)[9]. However, the authors have proposed that individuals and society are connected by practices in time and space. As they pointed out, social life can be represented as - "a series of ongoing activities and practices that people carry on, which at the same time reproduce larger institutions" (ibid, 1998, p.76). Nevertheless, individual subjectivity continues to be the core of processes of structuration, reproduction and change (Spaargaren and Oosterveer, 2010).

An action can be recognized as a practice when three characteristics are present: material, meaning and competence (Shove and Pantzar, 2005). In addition, practices are linked to time and space (Shove *et al*., 2009). It is important to note that practices are not stable or predermined (Aldred and Jungnickel, 2013). They appear to be provisionally located in the person's routines. Indeed, perceptions such as comfort, cleanliness, convenience (Shove, 2003a) and lifestyle expectations may redefine practices. For example, as Shove (2003a) argued, laundry practices currently have been re-defined associating the freshness concept to laundry, as a "fresh" smell is linked to disinfection (ibid).

With regard to the energy context, there is an increasing interest in understanding the relationship between energy consumption and daily practices. New energy efficiency practices, for example, may enable occupants to meet increased expectations of comfort and changes in lifestyle instead of decreasing energy consumption. (See section 2.3 - Take back effect). As some authors have emphasized, these practices will be the consequences if a new redefinition of thermal comfort is made,- "What if people expect to be even warmer during the winter and even cooler during the summer?" (Hunt and Gidman,1982 as cited inChappells and Shove, 2005, p. 37)

[9] According to Giddens (1988) – "In the past it was usually seen as a dualism between individual and society, or the actor and the social system" (Giddens, 1988, p.75)

It is thus reasonable to consider the extent to which household practices shape energy efficiency measures. This link between practices and energy efficiency measures is particularly relevant since energy efficiency governance as a result of low carbon transition in the UK has led to more efficient technologies in the domestic sector.

4. Modelling energy consumption

Urban energy systems have been defined as – *"the combined processes of acquiring and using energy in a given society or economy" (*Jaccard, 2005, p.6 reviewed in Keirstead and Shah (2013, p.24)). This definition highlights the fact that a system, which delivers energy services (*'combined processes'*), incorporates supply and demand balance (*'acquiring and using')* and includes both societal and economic aspects (Keirstead and Shah, 2013, p. 24). Urban energy system models offer analysis and understanding of the potential futures of these systems (Shackley *et al.*, 2002; Shah, 2013).

In addition, energy modelling offers a wide opportunity to simulate the impact of new infrastructure technologies and energy-efficiency retrofits in buildings (Hamilton et al., 2010; Keirstead and Sivakumar, 2012), in a spatial and temporal distribution of resource demands (Keirstead and Sivakumar, 2012). One of the greatest challenges for energy consumption models is how to capture behavioural responses to energy efficiency and demand side response policies. To date the influence of occupants (practices) on energy consumption has been badly represented in energy models. Indeed, they often have been criticized for the lack of simulation capabilities to recreate human practices or behaviour responses (Malkawi, 2004; Crawley et al., 2008).

This paper proposes that the effect of household practices can be captured in the form of energy saving and demand side flexibility (DSF), which are quantifiable and may be incorporated in energy models. It is expected, therefore, that an activity-based model will capture daily household level routines. Activity-based modelling can be defined as a – *"conceptual framework or a modelling paradigm with the objective of developing a behavioural and individual-level of demand"* (Sivakumar, 2013, p. 205).

This modelling framework has been used previously in land urban transport model systems (LUT) to predict demand for travel (Sivakumar, 2013). Travel demand management has increasingly concerned with analysing the potential of policies which comprehend behavioural responses at an individual/household-level (Pinjari and Bhat, 2011). By collecting bottom up information (e.g. travel times, out of home activities) this modelling paradigm enables the testing of the effectiveness of a given policy (Sivakumar, 2013) simulating for example peak time pricing or shift work schedules on individual travel behaviour (Pinjari and Bhat, 2011).

LUT systems are often based on a probabilistic approach, micro-economics, heuristic or combinations of these approaches (Sivakumar, 2013). For example, TASHA - Travel activity scheduler for household agent - developed by Miller and Roorda (2003) for Toronto, uses heuristic rules and econometric models to forecast travel demand. The authors focused on the idea of a project which organizes activity episodes (i.e work, school, shopping, return home episodes) into the person scheduler (ibid). Each activity episode in turn, has the following attributes such as activity type, start time, duration, location and episode mode.

Keirstead and Sivakumar (2012) simulated electricity and natural gas demands for London, using an adapted Travel activity scheduler for household agents - TASHA- developed by Miller and Roorda (2003). London's model used input data provided by a synthetic population of approximately 65,000 agents (2.5% of the population). Observed distributions focused on age, gender, education level, occupation type and employment status status (Keirstead and Sivakumar, 2012) .

Furthermore, the number of travel zones, the activity and residential housing provision in each zone, and the physical network connection derived from London Transportation Studies (ibid). In contrast to the TASHA model for Toronto, London's model lacked data to fill episodes attributes (frequency, duration, start time), however travel data from Toronto's model were assumed to be a good proxy for this model (ibid). Finally, London's model generated as an output of a list of episodes (e.g. work episodes, school episodes, joint other episodes and so on) along with its attributes, start time, duration, activity, location, and number of adults (ibid).

According to the authors, there are at least two approaches for calculating resource demands based on schedules; 'models of building energy demands and simulated occupancy' and regression models (Keirstead and Sivakumar, 2012, p. 893). Using a regression-based approach, they illustrated how activity-based modelling can be used to integrate demands with a detailed resolution (Keirstead and Sivakumar, 2012). This enables an assessment of different policies with regard to resource demands, such as travel patterns, and generates "resource demand profiles".

The model has shortcomings, including that it has not incorporated temperatures and time-dependent loads in the different buildings (Keirstead and Sivakumar, 2012) and the scheduler only considers out-of-home activities (i.e. the model is unable to simulate resource demand in-home). London's model proposed a different assessment of energy demand with a bottom-up approach.

4.1 Practice and Challenges at local level

This section explores the contribution of urban energy system models to Newcastle's aim of reducing carbon emissions by 20 per cent by 2020 using a 2005 baseline (NCC, 2010). The North East local authorities have pioneered the use of the VantagePoint (VP) modelling tool in the the development of energy policy (Calderon and Keirstead, 2012; Keirstead and Calderon, 2012) which is- *"designed to provide a cross-sectoral technology package that could deliver a defined carbon target by a specific date (e.g. 2020) for a local authority"* (Calderon and Keirstead, 2012, p. 510).

The tool can be used to manage energy policy interventions in accordance with local authority priorities and the development of carbon reduction scenarios under a mix of technologies (Calderon and Keirstead, 2012). However, VP has limitations and constraints related to the creation of different scenarios (e.g. minimum cost) and the inclusion of a mixture of technologies (e.g. installation rates of key technologies) (Keirstead and Calderon, 2012).

Keirstead and Calderon (2012) therefore proposed a new modelling framework, using an optimization model to evaluate and predict the urban energy systems in Newcastle upon Tyne. Their lowest cost optimization model incorporated policy constraints, such as 80% carbon emission target saving by the year 2050 and interim goals for simulation of the energy system (Keirstead and Calderon, 2012; Keirstead and Shah, 2013). It is based on the model called TURN (Technologies and Urban Resource Networks), which relies on a mixed integer linear programming (MILP) (Samsatli and Jennings, 2013). The model was used to predict the lowest cost energy system under two technology scenarios; '*demand side measures*' and '*supply side measures*' (Keirstead and Calderon, 2012, p. 256).

Principally, it suggested that the same measures be undertaken in different amounts, for example they proposed the installation of 47,700 loft insulation and 47,600 solid wall insulation. In addition, the use of renewable energy technologies (RET), such as photovoltaics, in 8,000 houses was also projected. As can be seen in Table 1, the results indicate that the main differences between VantagePoint and the TURN solution are based on inclusion of RET, Combined heat and power (CHP) and a different insulation mix (ibid).

Keirstead and Calderon referred to the importance of controlling the growth of electricity demand and the installation of efficiency measures (2012, p266). Although TURN provides relevant information for strengthening local energy policies, this can be considered to be a preliminary projection, as there are a number of challenges in terms of uncertain data and assumptions (Keirstead and Shah, 2013). For example, the authors pointed out the uncertainties produced by new technologies, and emphasised the need for discussion of the results with policymakers and stakeholders (ibid).

Table 1. Projection of changes to the Newcastle energy system to achieve 20% carbon reduction by 2020. A comparison between VantagePoint and TURN models. (Keirstead and Calderon, 2012, p. 267).

		VantagePoint	TURN
Demand side measures			
Behavioural change	Homes	1 11 225	1 11 225
Loft insulation	Homes	41 000	47 700
Double-glazing	Homes	20 000	8000
Cavity-wall insulation	Homes	27 000	14 500
Solid-wall insulation	Homes	10 000	47 600
Supply side measures			
Non-condensing boiler	Homes	51 200[a]	51 200
Condensing boiler	Homes	55 600[a]	56 900
Electric heater	Homes	4500[a]	–
District heating	Homes	–	1000
Air-source heat pump	Homes	–	–
Ground-source heat pump	Homes	500	–
Solar hot water	Homes	5000	8000
Photovoltaics	Homes	3000	8000
Domestic biomass boiler	Homes	500	3000
Commercial biomass boiler	MW_{th}	1	–
Building CHP	MW_e	15	5.3

[a] Assumed no change since 2005, as not specified in VantagePoint analysis.

Newcastle upon Tyne council has developed a technology-driven roadmap for retrofitting energy interventions in the city's building stock. Similarly, there have been a number of social science and policy governance studies which describe how local actors, such as community, local government, non-governmental organizations, and individuals, influence the decision making process in a defined urban energy system (Davoudi and Brooks, 2012). The interplay between a retrofitted technical system(s), social science and policy governance has, however, been less researched in the context of Newcastle upon Tyne.

5. Case study in Newcastle upon Tyne

The proposed methodology aims to use the theoretical framework (Figure 1) to answer the following questions: 1) How do household practices and demand side flexibility affect heating-related energy consumption in response to imposed retrofitted measures in social housing? 2) Can activity-based modelling (A-BM) predict heating-related energy consumption in imposed retrofitted social housing?.

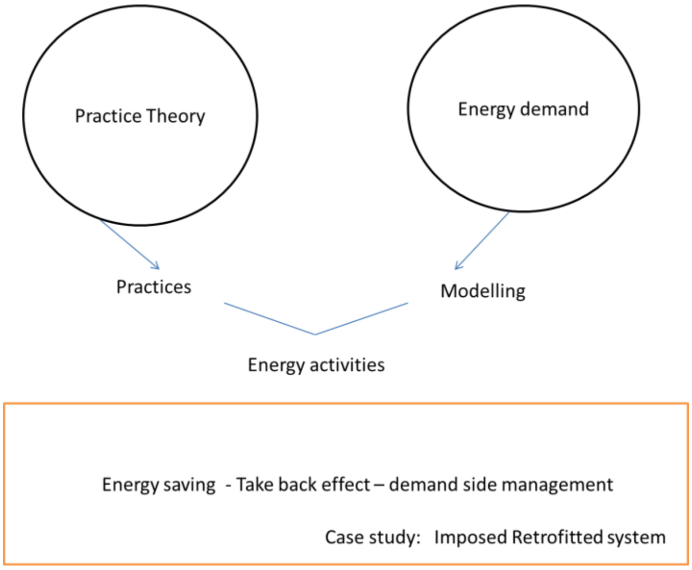

Figure 1. Theoretical framework.

Figure 2 shows the energy demand modelling framework in its proposed spatial and societal contexts.

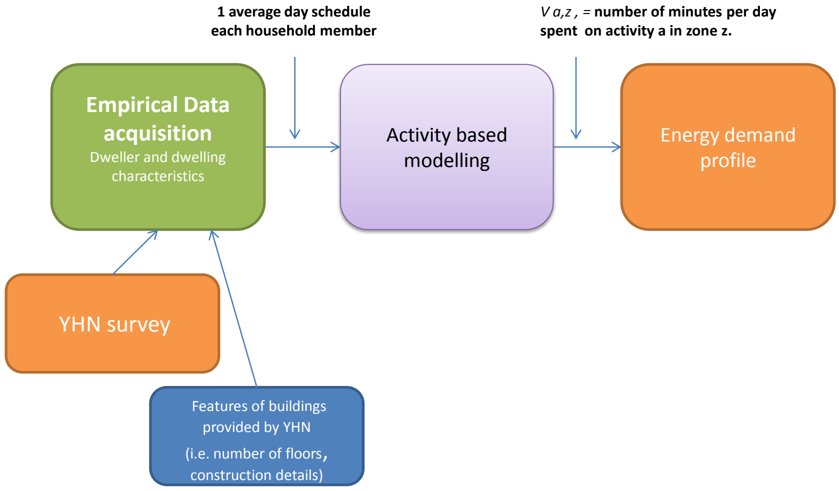

Figure 2. Energy demand modelling framework

5.1 Empirical data acquisition

The aim of the empirical data acquisition is to improve comprehension of how residents consume energy through household practices and produce initial parameters for the simulation of the energy demand. This empirical data will be collected by means of a survey specifically designed to produce specific data in a given location and with a specific target group. This survey has been chosen as the method for collecting the data for several reasons. Firstly, the activity-based model requires information representing general scheduling in order to draw up projects. Secondly, from a theoretical standpoint, it provides a systematic and objective method for gathering and analysing data.

This information will be collected from social sector housing to model energy demand as part of an on-going project between Your Homes Newcastle (YHN) (responsible for managing council housing on behalf of Newcastle City Council) and Newcastle University. The study will be based on a sample of 200 flats, which will be divided into two groups: non-retrofitted buildings and retrofitted buildings. 100 door to door surveys will be carried out for each group. The survey will collect information from each household member and the expected count will be around 400 people, as it is expected that each flat will be occupied by a maximum of two people.

This technique is highly appropriate since response rates are normally high and respondents have an interaction with the interviewer, enabling them to seek clarification of issues they may be unclear about (Trochim and Donnelly, 2008). This is, however, highly labour intensive and expensive, therefore a maximum of 200 flats will be surveyed. As a result, it is not expected that the sample will be representative of English households, rather the data will allow for the testing of a methodological framework to include bottom-up information in disaggregated model energy systems.

Initial data will be collected using a tablet-based questionnaire. The first section will be related to respondent characteristics, such as household composition and household income. The second section will include a list of factors which, according to previous studies, have been perceived as improvements after solid wall retrofitting, such as level of warmth, draught, noise, quality of life, external appearance of building and incidence of cold-related diseases. In the last section, the respondents will be asked to describe their daily practices and routines at home on an average winter's day.

Activities have been classified into five main topics: basic needs, work/school activities, household obligations, entertainment and others. Entertainment activities, for example, including hobbies at home, surfing on the internet, exercising, reading for pleasure and social meetings, will be included in this section. This information, together with the building features data, which will be provided by YHN, will be used to profile the sample and analyse similarities and differences between energy efficiency behaviour in the retrofitted and non-retrofitted stock.

The study will seek to understand the impact of the activities/routines on energy demand and compare properties which have received solid wall insulation with those which have not yet received the intervention. Only similar dwellings and dwellers will be considered, i.e. social sector housing managed by YHN, comprising one or two bedroom flats holding a maximum of two people, similar flat size and building features (e.g number of floors, common services such as lifts, car parking), properties with age restriction (only tenants over the age of 55 years are renting these flats) and with the same Economy 7 heating system.

The buildings likely to be surveyed are two buildings which received solid wall insulation and double glazing during the past two years, and another two buildings expected to have solid wall insulation installed during the course of the next year. It is expected that tenants will have similar social status, gender distribution and employment status (for example retired people). See summary of methodology control in Table 2.

Table 2. Summary of methodology control.

Parameters	Retrofitted buildings, Solid wall and double glazing (2 buildings)	Non retrofitted buildings (2 buildings)
Sample	100 flats	100 flats
Heating system	Economy 7 (electricity)	
Flat size and distribution	1 or 2 bedrooms flats	
Age group	Buildings comprising people with an age restriction of over 55	
Similar socio economic characteristics	Social housing managed by Your Homes Newcastle	
Employment status and Tenure	Retired people renting social houses	
Family living at the current residence.	At least 1 ½ years (*)	

(*) This information is relevant to link energy bills to residents over the same period.

5.2 Conceptual Model

This section of the paper describes a proposed conceptual model framework which was derived from theoretical insights and will be improved after the survey data are gathered. The focus of this framework is on simulation of domestic sector energy demands at the micro level. The conceptual model interacts with an activity-based model (as described in the following sections). The methodological approach is summarised in Figure 3, which shows the model input, model process and model output.

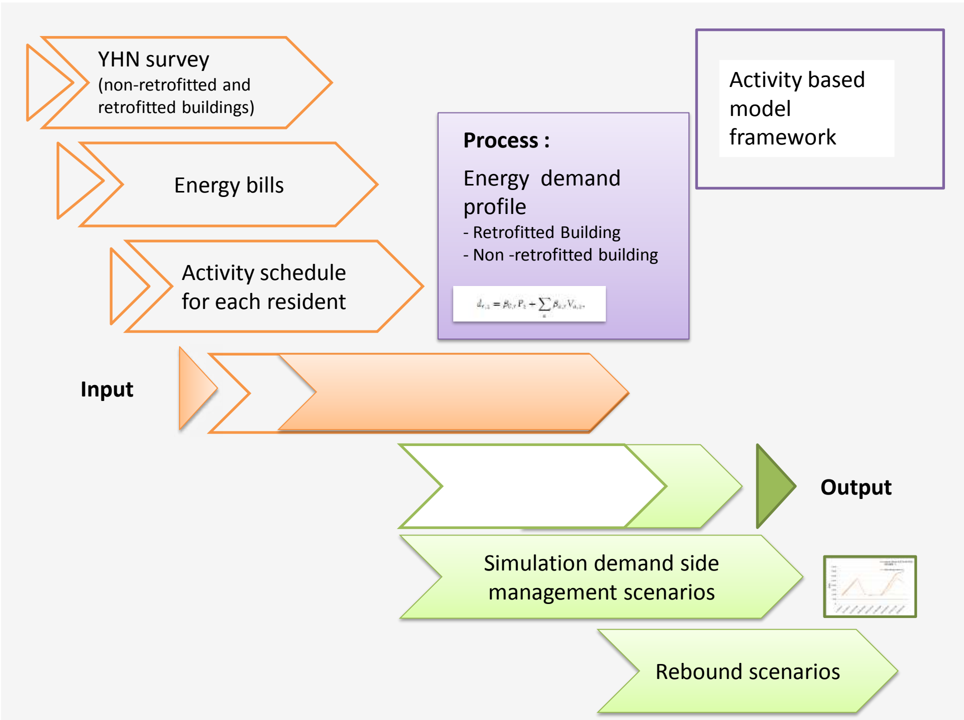

Figure 3: Methodological aproach.

5.2.1 Model Input

In order to calculate the energy demand in a spatial and societal context using the activity-based model (described in section 3.3), the TASHA software, developed by Miller and Roorda (2003) to model urban transport models, will be adapted for the purposes described in this paper. Each resident will be assigned to one of four zones in accordance with their location.

The survey described above will provide information relating to an activity schedule timed between 6 AM to 12 AM for each resident, broken into 2 hour intervals, which will include information regarding shared and individual activities, the times at which activities are performed and their duration. Each daily activity schedule drawn from the survey will be codified to be transformed into a "txt extention file", for example activity (e.g. shower=1), start time (e.g. 7:00 AM=10), duration (e.g. 15 min=15) and number of adults (e.g 1). Socio-demographic characteristics such as age, gender and employment and education status and education will also be generated from the survey data.

5.2.2 Model process

This section describes the conversion of activity schedules (inputs) into energy demands. ENERGY-TASHA will generate as an outcome, a file with a list of episodes (e.g. mealtime activities, home duty, personal care and so on), along with its attributes: start time, duration, activity, location, and number of adults. Then Energy demand may be forecasted following the method used for London by Keirstead and Sivakumar (2012) and focusing on activities within households:

$$d_{r,z} = \beta_{0,r} P_z + \sum \beta_{a,r} V_{a,z} \quad (2)$$

where $d_{r,z}$ = annual average daily demand for electricity r in zone z;
P_z = observed population of each zone z;
$V_{a,z}$ = time spent (minutes per day) on in home- activities (a) within households in zone z;
$\beta_{x,r}$ = the regression coefficients for resource *r.*

Calibration of the model will rely upon 1.5 years energy demand data obtained from electricity bills from residents. Data of this type, however, is not publicly available and requires permission to be obtained from the residents to gain access to providers such as British Gas, E.ON, Scottish Power and other providers of energy.

The calculation considers energy demand activities which are a function of the household members' daily schedules such as taking a shower or watching TV and calculation of energy demand also has to include "passive" energy consumed by non-stop devices, such as a freezer or internet modem which are switched on all day.

It is important to note that, as an ongoing research study at a further stage, the initial approach presented should be evaluated, taking into account the following several limitations such as the limitations of the regression model used by Keirstead and Sivakumar (2012), which is not sensitive to temperature changes and assumes that, in the following years, energy demand will increase it (ibid). In addition, the energy considered in the building sample are completely provided by a source of electricity, since the heating system in this case study uses the tariff Economy 7 (which means that these buildings use electricity to build up heat in the storage heaters at night, and releases the heat in the daytime).

In addition, as was mentioned in the previous paragraph, energy consumption does not include features of the flat (type, size and insulation of the flats), however, these buildings have a similar construction type. Furthermore, the model does not establish the effects of shared activities (for example watching TV) and overlapping activities (e.g. washing the clothes, taking a shower and cooking at the same time).

As the energy practices that will be considered in the model prediction will be based on winter energy consumption, some practices and their equivalent energy demands may be overestimated or underestimated, compared with average annual consumption.

5.2.3 Output

As proposed above, this model intends to answer the following questions: How do household practices and demand side flexibility affect energy consumption in response to imposed retrofitted measures in social housing? The characteristics of the case study, in which energy is entirely supplied by electricity, makes it very difficult to differentiate electricity used for space heating, from that for water heating or lighting. However, it is expected that, once the energy demand is estimated, a simulation of the different demand side management scenarios or "flexible" practice scenarios can be undertaken.

Some routines will be modified for observation of their possible impact on energy demand, for instance washing activities during peak hours will be adjusted to that of time saver. Figure 4 shows a possible simulation scenario of the impact on energy demand if a retrofitted household adjusts their washing cycle to time saver (i.e. 15 or 20 minutes). In this hyphothetical scenario, the projected energy demand is decreased by time saver activities. In addition, practices such as changing the duration of the shower, cleaning, switching off lights or moving activities to off-peak hours can be also modelled.

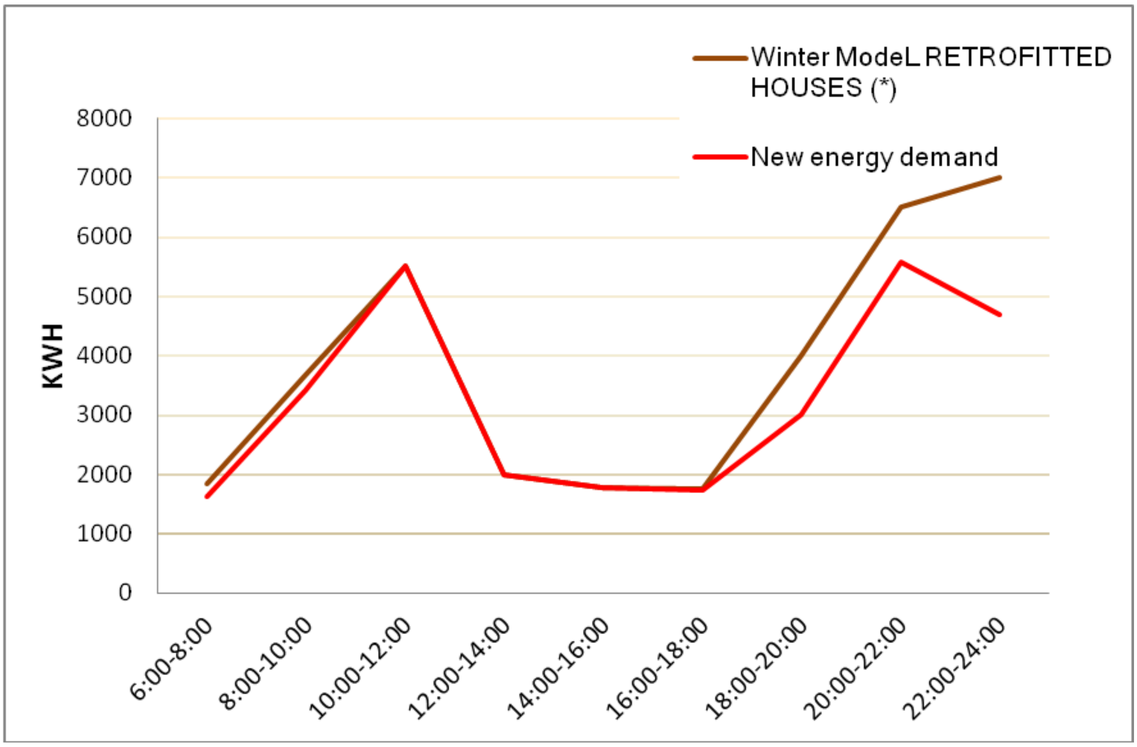

Figure 4: Comparation of energy demand model business as usual v/s projected time saver energy model for a retrofitted house.

In addition, the take back effect will be reviewed, taking into account the difference between energy demands (See Figure 5) and practices in non-retrofitted and retrofitted households. In theory the combination of solid wall and double glazing insulation will result in a reduction of the energy demand. However, a possible scenario is shown in Figure 5, as a result of people increasing their energy consumption in the evenings, because they are able to carry out more activities and are going to bed later in retrofitted buildings

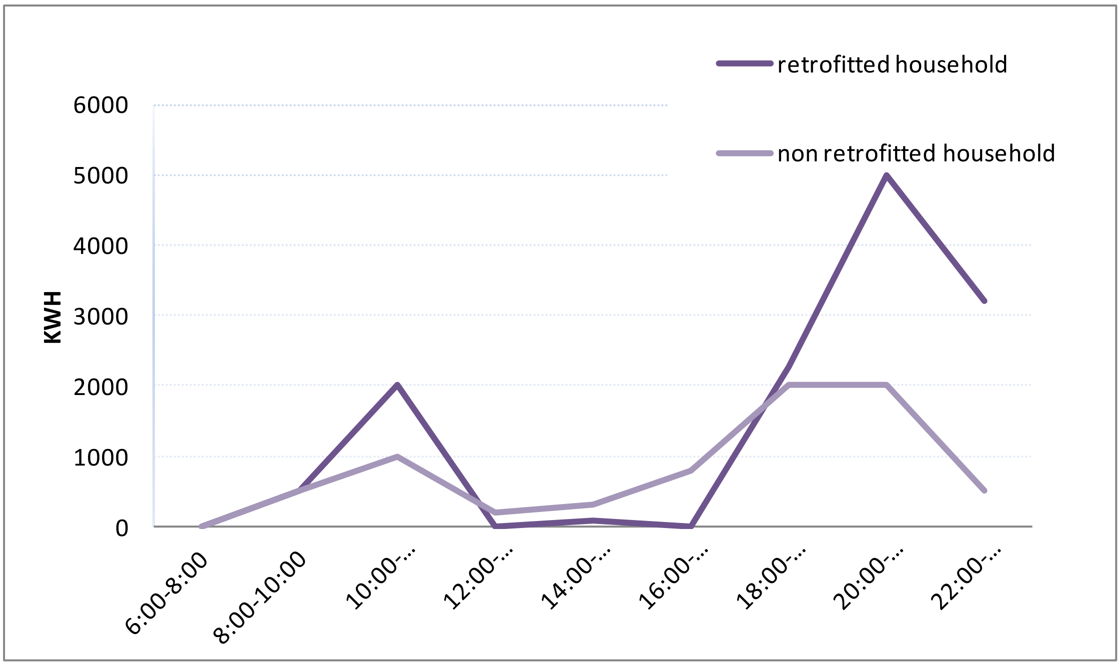

Figure 5: Comparation of non-retrofitted and retrofitted household energy demand.

This research will also review whether some practices have been incorporated into the routines or have experienced a relevant change, for example if people are going to bed later in retrofitted buildings, they are going to increase their energy consumption (See figure 5).

6. Conclusion

This paper has sought to consider new challenges for energy demand models, proposing a highly disaggregated bottom-up approach. Newcastle City's commitments made in the "EU Covenant of Mayors" to reduce carbon emissions by 20% by 2020 Newcastle (Newcastle City Council, 2010) and the UK low carbon agenda requires major improvement of the energy efficiency measures of the existing stock by means of retrofitting schemes such as solid wall insulation. However, improvements may not be able to achieve the estimated reductions in energy demand, on account of the take back effect.

Therefore, this paper has proposed the carrying out of a study to develop a better understanding of how household practices and demand-side flexibility affect energy demand. The modelling framework for this case study is based on an activity-based model framework, which has been previously used in the modelling of urban transport systems. It is proposed that bottom-up information be collected by means of a survey, which will provide data to understand the daily practices in two groups of social housing dwellings (non retrofitted flats and solid wall retrofitted flats), as part of an on-going project between Your Homes Newcastle and Newcastle University.

The main outcome of this research study will be the modelling of energy demand at residential level in a spatial and societal context, based on activity types and their duration. The model can then be used to evaluate "what if" scenarios in demand-side management e.g. adjusting practices such as cleaning or washing. This also allows for analysis of the rebound effect. Limitations and shortcomings in the current methodology have been also discussed, such as including "passive" energy consumed by non-stop devices and energy consumption being completely provided by an electricity source. In addition, other factors which affect space heating such as the features of the house, weather conditions and counting of shared and overlapping activities have also been covered.

References

Alcott, B., Giampietro, M., Mayumi, K. and Polimeni, J.M. (2012) *The Jevons Paradox and the Myth of Resource Efficiency Improvements*. London: Earthscan.

Aldred, R. and Jungnickel, K. (2013) 'Matter in or out of place? Bicycle parking strategies and their effects on people, practices and places', *Social & Cultural Geography*, 14(6), pp. 604-624.

Calderon, C. and Keirstead, J. (2012) 'Modelling frameworks for delivering low-carbon cities: advocating a normalized practice', *Building Research & Information*, 40(4), pp. 504-517.

Chappells, H. and Shove, E. (2005) 'Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment', *Building Research & Information*, 33(1), pp. 32-40.

Davoudi, S. and Brooks, E. (2012) *Environmental Justice and the City: Full Report*.

DECC (2011) *What measures does the Green Deal cover?* London.

DECC (2012) *Final Stage Impact Assessment for the Green Deal and Energy Company Obligation*. London.

DECC (2013) *The Green Deal. A way for owners and tenants to pay for home improvements*. London.

Druckman, A. and Jackson, T. (2008) 'Household energy consumption in the UK: A highly geographically and socio-economically disaggregated model', *Energy Policy*, 36(8), pp. 3177-3192.

Giddens, A. and Pierson, C. (1998) *Conversations with Anthony Giddens: Making sense of modernity*. Stanford University Press.

Guy, S., Marvin, S. and Moss, T. (2001) *Urban infrastructure in transition: networks, buildings and plans*. Earthscan.

Higginson, S.L., Richardson, I. and Thomson, M. (2011) 'Energy use in the context of behaviour and practice: The interdisciplinary challenge in modelling flexible electricity demand'.

IEA (2011) *Implementing Agreement on Demand-Side Management Technologies and Programmes 2011 Annual Report*. Paris: International Energy Agency. [Online]. Available at: http://www.ieadsm.org/Files/Exco%20File%20Library/Annual%20Reports/REV.Annual%20report_2011C_lag.pdf (Accessed: 11 September 2013).

Jennings, M. (2013) 'Building energy service demands: the potential of retrofits', in Keirstead, J. and Shah, N. (eds.) *Urban Energy Systems: An Integrated Approach*. London: Routledge.

Kane, T., Firth, S.K., Allinson, D., Irvine, K. and Lomas, K.J. (2011) *World Renewable Energy Congress*. Linköping, Sweden, 11 May 2011.

Keirstead, J. and Calderon, C. (2012) 'Capturing spatial effects, technology interactions, and uncertainty in urban energy and carbon models: Retrofitting Newcastle as a case-study', *Energy Policy*, 46, pp. 253-267.

Keirstead, J. and Shah, N. (2013) *Urban Energy Systems: An Integrated Approach*. Routledge.

Keirstead, J. and Sivakumar, A. (2012) 'Using Activity‐Based Modeling to Simulate Urban Resource Demands at High Spatial and Temporal Resolutions', *Journal of Industrial Ecology*, 16(6), pp. 889-900.

Mayor of London (2014) *The Future of the Energy Company Obligation. Consultation response from the Mayor of London, April 2014*. London.

Miller, E.J. and Roorda, M.J. (2003) 'Prototype model of household activity-travel scheduling', *Transportation Research Record: Journal of the Transportation Research Board*, 1831(1), pp. 114-121.

Newcastle City Council (2010) *Citywide Climate Change Strategy and Action Plan 2010 Trust*. Newcastle: Newcastle City Council.

Ofgem (2013a) *The final report of the Carbon Emissions Reduction Target (CERT) 2008-2012*.

Ofgem (2013b) *The final report of the Community Energy Saving Programme (CESP) 2009-2012*

Rosenow, J. (2012) 'Energy savings obligations in the UK—A history of change', *Energy Policy*, 49(0), pp. 373-382.

Rosenow, J. and Eyre, N. (2012) *9th BIEE Academic Conference, Oxford*.

Samsatli, N. and Jennings, M. (2013) 'Optimization and systems integration', in Keirstead, J. and Shah, N. (eds.) *Urban Energy Systems: An Integrated Approach*. Routledge.

Sanders, C. and Phillipson, M. (2006) *Review of differences between measured and theoretical energy savings for insulation measures*. Centre for Research on Indoor Climate and Health, Glasgow Caledonian University, Glasgow.

Shackley, S., Fleming, P. and Bulkeley, H. (2002) *Low carbon spaces area-based carbon emission reduction: a scoping study*. Sustainable Development Commission.

Shah, N. (2013) 'Modelling urban energy system', in Keirstead, J. and Shah, N. (eds.) *Urban Energy Systems: An Integrated Approach*. Routledge.

Shove, E. (2003a) *Comfort, Cleanliness and Convenience: The Social Organization of Normality (New Technologies/New Cultures)*.

Shove, E. (2003b) 'Users, technologies and expectations of comfort, cleanliness and convenience', *Innovation: The European Journal of Social Science Research*, 16(2), pp. 193-206.

Shove, E. and Pantzar, M. (2005) 'Consumers, Producers and Practices Understanding the invention and reinvention of Nordic walking', *Journal of consumer culture*, 5(1), pp. 43-64.

Shove, E., Trentmann, F. and Wilk, R. (2009) *Time, consumption and everyday life: Practice, materiality and culture*. Berg.

Sivakumar, A. (2013) 'Activity-based modelling for urban energy system', in Keirstead, J. and Shah, N. (eds.) *Urban Energy Systems: An Integrated Approach*. London: Routledge.

Spaargaren, G. and Oosterveer, P. (2010) 'Citizen-Consumers as Agents of Change in Globalizing Modernity: The Case of Sustainable Consumption', *Sustainability*, 2(7), pp. 1887-1908.

Trochim, W.M.K. and Donnelly, J.P. (2008) *Research methods knowledge base*. Atomic Dog/Cengage Learning Mason, OH.

Vale, B. and Vale, R. (2010) 'Domestic energy use, lifestyles and POE: past lessons for current problems', *Building Research & Information*, 38(5), pp. 578-588.

Wilhite, H., Shove, E., Lutzenhiser, L. and Kempton, W. (2000) 'The legacy of twenty years of energy demand management: we know more about individual behaviour but next to nothing about demand', in *Society, behaviour, and climate change mitigation*. Springer, pp. 109-126.