# Modelling Approaches for Retrofitting Energy Systems in Cities: Current Practice and Future Challenges in Newcastle upon Tyne

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**Abstract**: The paper reviews the UK carbon agenda and current local practices and challenges in urban energy modelling as to highlight the lack of models and quantitative understanding of the interplay between technical and social systems. The paper also reviews existing modelling household practices and energy demand to contextualize the emphasis of our study (i.e. take back effect and demand-side management) and the rationale behind our selected approach: activity-base model. The model is used to model and quantify two salient aspects of the interaction between retrofitted technical systems and household practices: (1) take back effect; and (2) demand-side management. By applying the model, the paper presents a case study using 200 social households in Newcastle upon Tyne. Finally, we propose a theoretical model and its detailed implementation. The modeling results have important theoretical and practical implications for the development of planning decision support system for urban regeneration.

**Keywords**: Urban Regeneration; Urban Energy Consumption; Energy Consumption Model; Rebound Effect; Demand Side Management

## Introduction

The UK low carbon transition plan has set stringent carbon national targets (i.e. an 80% reduction in GHG emissions by 2050) which rely on achieving a zero-carbon housing stock. Currently, in the UK, households account for 27% of total carbon dioxide emissions (HM Government, 2006 as cited in Druckman and Jackson (2008)). The domestic sector is therefore an important sector. Thus far, retrofitting energy efficiency interventions in houses has been the main priority of policy makers. As a result, a considerable amount of research has gone into understanding the potential benefits (e.g. carbon savings, cost, etc) of retrofitting energy efficient technologies in the domestic stock (See for example, Jennings, 2013). Additionally, a growing body of academic research has been accumulated on governance, social and behavioural practices in households as to describe and contextualize domestic dwelling practices around usage of energy (See for example Kane et al., 2011). However, the interplay between a retrofitted technical system(s) (e.g. a solid wall insulation) and household practices (e.g. daily activities such as cooking, having a shower and so on) has not been as widely explored and, to the best of our knowledge, not been modelled and/or quantified at the dwelling scale.

This paper proposes an activity-based model framework as to model and quantify two salient aspects of the interaction between retrofitted technical systems and household practices: 1) take back effect; and 2) demand side management. To correlate theory and practice, a case study using 200 social households in Newcastle upon Tyne will be carried out. Bottom up information will be collected in solid wall retrofitted and non-retrofitted social houses and it is expected this approach will enable a better understanding of the 'Take back effect' (The increase in energy consumption, as a result of improvements in energy efficiency measures)of retrofitted technologies and demand side management, focusing on 'flexibility' of practices (i.e. 'What-if' scenarios, in order to identify which household practices have the potential to engage end users to improve the management of the grid).

The paper is structured as follows. We first briefly review the UK carbon agenda and current local practices and challenges in urban energy modelling. We then focus on modelling household practices and energy demand to contextualize the emphasis of our study and the rationale behind our selected approach: activity-base model. Finally, we propose a conceptual framework and its detailed implementation.

# 1 Background: Low Carbon Agenda

The UK Government is seeking to address the low carbon agenda (Reducing the UK's greenhouse gas emissions by 80% by 2050) by focusing on the existing buildings for a low carbon retrofitting. However, before exploring the different energy policies and retrofitting programmes, it is essential to define retrofitting. The concept of retrofitting insulation refers principally to improvements in the energy efficiency and carbon reductions in buildings (Rhoads, 2010). This paper will use the definition by Jennings (2013) who described retrofit as – "*... is used when referring to planned improvements to existing buildings by means of altering, replacing or removing an existing technology or technologies …*" (Jennings, 2013, p. 59).

With regard to energy, retrofit is intended to contribute to the reduction of current energy demands and improve the efficiency of supply (Jennings, 2013). Depending on the retrofit building-scale it is possible to distinguish different between the benefits which range from "individual demand-side measures" to "centralized supply side technologies" (Jennings, 2013, p. 60). For instance, the retrofit benefits for supply side management can include renewable technologies such as wind energyor solar photovoltaic (PV). In addition, decreased heating requirements as a result of upgrading external insulation on small building-scale should generate benefits on the demand side.

A wide range of further policy measures aimed at retrofitting measures have been designed to support the strategy for low carbon housing. Indeed mechanisms such as the Carbon Emissions Reduction Target (CERT) and the Community Energy Savings Programme (CESP), which have been replaced by Green Deal and Energy Company obligation-ECO have been mobilizing private and public financial investment for retrofitting programmes in the domestic sector. At a local level, in 2010, Newcastle City Council (NCC) signed the "EU Covenant of Mayor" (Newcastle City Council, 2010), which committed the council to develop a Sustainable Energy Action Plan (SEAP) to reduce carbon reductions by 20% by 2020 from a 2005 baseline (using NI186 scope) – *"Newcastle's carbon footprint is approximately 1.9 million tonnes of CO2 per year as measured in 2005 by the national indicator NI186"* (Newcastle City Council, 2010, p. 2).

Initially, in 2004, the Council started operating the Warm Zone Initiative, which principally concentrated on fuel poverty. This was followed by, the Climate Change Strategy (Newcastle City Council, 2010), launched in 2010, which included 'the domestic housing work stream', and involved different energy-related initiatives, such as existing infrastructure retrofitting schemes (Davoudi and Brooks, 2012) and offered various programmes aimed at the residential sector and the Carbon route map project (Newcastle City Council, 2010). More than 45.000 homes have been retrofitted (Keirstead and Calderon, 2012) and a Carbon map strategy has been developed which includes future retrofitting projects (Keirstead and Calderon, 2012), however, to date mainstream retrofitting programmes have only focused on cavity and loft insulation (Keirstead and Calderon, 2012) also known as **-** 'low hanging fruit', as key energy efficiency measures (Ibid).

The next step will be to determine how local authorities reshape a new role in the 'Green Deal scenario'. ANEC[1] authorities have already commenced to explore this type of scheme. Indeed, in terms of funding they have been working with grants such as ELENA (circa £2m technical grant) to secure EIB loans (or other sources of loans) for investing in low carbon measures (Calderon, 2011). According to local authorities this policy can be strengthened in time by developing an area base approach, which can contribute to understanding the different housing stock, targeting housing types that will offer the greatest $CO_2$ savings and prioritising the development of models for these homes (Ibid).

Bottom-up (BU) strategies (area based approach) are expected to facilitate the transference of national and city carbon reduction targets into street level improvement plans. According to (Shackley *et al.*, 2002) BU strategies offer an improvement on the decision making process and foster community involvement (Shackley *et al.*, 2002). However, different obstacles can be found, for instance the authors drew attention to different barriers such as **-** "*The energy-embeddedness of*

[1] Association of North East Councils: An association of 12 local authorities in the North East of the UK.

*technologies, buildings, infrastructures and material possessions, as well as short*termism in managerial and economic decision-making, transaction costs, lack of personnel time and life-style expectations*"* (Shackley *et al.*, 2002, p. 48).

# 2 Practice and challenges

This section explores the contribution of urban energy system models to new challenges in the North East (UK), specifically in Newcastle upon Tyne, to reduce carbon emissions by 20 per cent by 2020 Newcastle (Newcastle City Council, 2010). However, before exploring this interconnection, it is essential to point out that urban energy system models offer the ability to analyze and gain a better understanding of the situation, in order to predict the future conditions of these systems (Shackley *et al.*, 2002; Shah, 2013). In addition, 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). As Keirstead and Shah (2013) stated, this definition highlights important characteristics such as a system which delivers energy services (*'combined processes'*), incorporates supply and demand balance (*'acquiring and using')* and includes societal and economic aspects (Keirstead and Shah, 2013, p. 24).

The North East's councils were pioneers in the UK in setting up a methodology for the development of their Sustainable Plan in the energy context (Calderon and Keirstead, 2012). Principally, the planning of urban systems has relied on VantagePoint (Keirstead and Calderon, 2012), which has been described as "*a tool designed to provides 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 authors pointed out that this tool allows for the management of the energy policy interventions in accordance with local authority priorities. Utilizing national indicators such as NI 186 (emissions baseline) allows for the development of carbon reduction scenarios under a mix of technologies (Calderon and Keirstead, 2012).

However, limitations have been described principally on the basis of proposed scenarios, such as 'criteria-based scenarios', technology constraints and long term periods predictions – "*... it provides limited guidance on the creation of criteria-based scenarios (e.g. minimum cost) and it is difficult to add important constraints on feasible technology mixes such as limitations on installation rates of key technologies. Also VantagePoint offers only a single view of the future...[]"* (Keirstead and Calderon, 2012, p. 254).

Furthermore, In 2012, Keirstead and Calderon (2012) proposed a new modelling framework, using an optimization model to evaluate and predict the urban energy systems in Newcastle upon Tyne (Keirstead and Calderon, 2012). The least cost optimization model incorporated policy constraints, such as 80% saving carbon emission targets by the year 2050 and interim goals for simulation of the energy system (Keirstead and Calderon, 2012; Keirstead and Shah, 2013). These types of models are increasing in importance (Keirstead *et al,* 2012a,c, reviewed in Samsatli and Jennings (2013)) and should also be taken into account in energy infrastructure planning. Indeed, policy-makers and urban planners need tools and procedures which can provide a '*foundation for an evidence-based approach to low-carbon urban transitions'* (Calderon and Keirstead, 2012, p. 4).

The projection proposed by authors in 2012 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 address by 2020, to address the issue of undertaking loft and solid wall insulation in 47700 and 47600 properties respectively (Ibid). In addition the use of renewable energy technologies (RET) such as Photovoltaic in 8000 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, CHP (Combined heat and power) and a different insulation mix, for example, double glazing (Ibid)(Table 1).

**Table 1:** Projection of the Newcastle energy system by 2020.A comparison between VantagePoint and TURN models

| | | 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.

Source: Keirstead and Calderon, 2012, p. 267

Furthermore the authors referred to the importance of -"*control the growth of electricity demand*" and "*the installation of efficiency measures as soon as possible*" (Keirstead and Calderon, 2012, p. 266). Although the method (Turn) provides relevant information for strengthening the local energy policies, this can be considered to be a preliminary projection, since there are a number of challenges in terms of uncertain data and assumptions (Keirstead and Shah, 2013). For example, the author pointed out the uncertainties produced by new technologies, which can be included in a period of 40 years, therefore he proposed the recognition, description and discussion of the results with policy makers and stakeholders (Ibid).

As a result of these studies, the city of Newcastle upon Tyne has developed a technologically driven roadmap for retrofitting energy interventions in the city and its building stock. Similarly, there have been a number of social science and policy governance studies as to describe how local actors such as community, local government, non-governmental organizations, and individuals, are interconnected and how they influence the decision making process in a defined urban energy system (Davoudi and Brooks, 2012). The interplay between a retrofitted technical system(s) and social science and policy governance has been less researched in the context of Newcastle upon Tyne. Indeed, recent investigations regarding technology diffusion and adoption concerned with this interplay are utilising agent-based models (ABM) as to model interactions between systems (i.e. technical and social) (See for example Zhang and Nuttall, 2007; Martinez-Moyano *et al.*, 2011; Maya Sopha *et al.*, 2011; Palmer *et al.*, 2013).

This type of simulation offers various advantages due to the bottom up approach, whereby different agents interact with each other and influence the decision, as in, for example -'*the captures emergent phenomena', 'provides a natural description of a system' and 'is flexible'* (Bonabeau, 2002, p. 7280). ABM provides the potential for simulating diffusion and adoption of new sustainable technologies, taking into account the complexity of interactions between agents at a spatial and temporal level. For example smart metering (Zhang and Nuttall, 2007) and heating systems (Maya Sopha *et al.*, 2011) models have suggested insights into future policies and strategies in the energy market. Likewise, different authors have been using models in the social sciences (See for example Axelrod (1997)) simulating human behaviour, however, the use and validity in the real world of simulation models is often questioned due to the lack of relevant behavioural theories (Jager, 2000). The same author, for instance, proposed a meta-model based on psychology theories which provided a set of rules and algorithms for an artificial agent called "Consumat" (Ibid). In the next section, we explore how the ABM concept ought to extended to better understand the interaction between technical and social systems.

# 3 Modelling household practices and energy demand

Changes in the level of comfort and lifestyle are expected to impact on the energy consumption. Indeed, according to some authors, there is a close relationship between energy consumption and changes in routines/habits (see Shove (2003)). In order to understand this interaction, sociologists have brought the link between energy consumption and everyday practices into the equation, using the theory known as 'practice theory' (See for example (Shove, 2003; 2007)). Some practices have become 'normal', in spite of being deemed unacceptable in the past, as factors such as comfort, cleanliness and convenience have changed their meanings and shaped collective conventions (Shove, 2003, emphasized in (Chappells† and Shove‡, 2005). – "*What if people expect to be even warmer during the winter and even cooler during the summer? (Hunt and Gidman, 1982 as cited in (Chappells† and Shove‡, 2005, p. 37).*

Therefore, new energy eff*iciency* practices may increase levels of comfort for occupants instead of decreasing energy consumption. It is thus reasonable to consider the extent to which practices will shape energy efficiency measures. In addition, the link between practices and energy efficiency measures is also a contingent topic since energy efficiency governance as a result of low carbon transition in the UK has led to a move to more efficient technology in the domestic sector. However, estimation of energy efficiency (EE) has neglected to take into account the 'Rebound effect' (Sorrell, 2007) and may not deliver the desired carbon emission reduction results, following an improvement after the implementation of retrofitting measures.

Finally, demand side flexibility as a means of integrating human practices (e.g. household practices) and technical systems (e.g. a smart grid, smart controls), may identify which household practices have the potential to engage end users in improving the management of the grid as regards when, where or how such practices are conducted (Powells *et al.*, 2013). This paper proposes that there should be a better developed estimation of heating energy consumption, together with comprehension of dwelling practices, the 'Take back effect' of retrofitted technologies and demand side flexibility.

## 3.1 Take back effect

The increase in energy consumption, 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, the Green Deal potential of social housing 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). Rebound effect can be defined as – "*a percentage of the expected energy savings from an energy efficiency improvement. So a rebound effect of 20% means that only 80% of the expected energy savings are achieved*" (Sorrel, 2007, p.6).

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 analysing diverse studies which consider the difference between actual and predicted energy saving following installation of better insulation:

Reduction factor (RF) = Comfort factor (CF) + Other factor (OF)

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 comfort factor varies depending on different studies (See for example; Shorrock *et al.*, 2005; Sorrell, 2007). Indeed, Sander and Phillipson (2006) suggested a 50% of RF, of which 15% is comfort factor, ie.:

Reduction factor (50%) = Comfort factor (15%) + Other factor (30%)

## 3.2 Demand side management

In the past, the energy supply response was often assumed to be a passive form (Guy *et al.*, 2001). For example, in the electricity context utility providers met increased demand through ‘supply oriented options’ (Ibid). However, nowadays the demand side management (DSM) offers new opportunities for promoting network member interactions ‘beyond-the-meter’ (Ibid). Most importantly, DSM presents the ability to transform the end-user from user into consumer (Ibid). For example, different authors have described options for altering the consumption pattern of electricity customers. Indeed, Gellings *et al.* (1986) used the concept of ‘electric demand-side management’ to explain the modification of consumption patterns and other author suggested in case of network congestion problems – “...*to reduce the level, or shift the timing, of peak consumption*” (Guy *et al,* 1996 reviewed in (Guy *et al.*, 2001, p. 33).

In the UK, the Green Deal programme (The Energy Act of 2011) and the introduction of smart metering have presented new opportunities for improving the energy efficiency and demand side response (IEA, 2011). Indeed, it is expected that once gas and electricity meters will be replaced, the improvement in terms of use of time and variable tariffs will be tangible (Ibid). Therefore, it is argued in this paper argue that ‘demand side flexibility’ plays an important role in DSM offering the potential to integrate Urban energy system models, since the practices may eventually be modified, and will engage end users in activities/routines that can allow for a reduction in the energy consumption.

## 3.3 Activity based models to capture energy demand side flexibility and measure take back effect

Principally, one of the greatest obstacles in the energy consumption models is how to capture behavioural responses to energy efficient and demand side response policies. In this instance, this paper proposes that it will be captured by means of household practices and assessment of demand side flexibility (DSF). It is expected, therefore, that an activity based model will capture the daily household level routines. Activity-based modelling (A-BMs) can be defined as a – “*conceptual framework or a modelling paradigm with the objective of developing a behavioural ad individual-level of demand*” (Aruna S., 2013, p. 205).

Travel demand management has been increasingly interested in analyzing the potential of policies which comprehend behavioural responses at an individual/household-level: for example, understanding the influence of individual travel behaviour when policies such as peak time pricing or alternate work schedules are applied (Pinjari and Bhat, 2011). TASHA's model, for instance, is a simulation which incorporates a travel activity/scheduler to forecast travel demand and focuses on the idea of a project[2] to approach models of behavioural processes (Miller and Roorda, 2003). Likewise, urban energy systems can benefit from ABMs, since this simulation provides a –"*behavioural approach to predicting resource demands that acknowledges their derived nature*" and "*the agent-based disaggregate approach provides high resolution detail, which serves as an effective input to integrated supply models*" (Aruna S., 2013, p. 217).

Indeed, Keirstead and Sivakumar (2012) simulated electricity and natural gas demands in London, using an activity scheduling model called TASHA (Travel activity scheduler for household agent) developed by Miller and Roorda (2003) for Toronto. Using a regression-based approach they illustrated how activity-based modelling can be used to integratedemands with a detailed resolution – "*at temporal resolutions of 5 minutes and spatial resolutions of approximately 2 ha*" (Keirstead and Sivakumar, 2012, p. 899). Principally this enables an assessment of different policies with regards to resources demands such as travel patterns and generates "resource demand profiles" (Keirstead and Sivakumar, 2012, p. 897). However, the authors also drew attention to shortcomings on in the capture of practices/routines at home, suggesting improvements which should be made to building energy consumption model (Ibid).

# 4 Case study in Newcastle upon Tyne

As was mentioned previously, this socio-technical research is aiming to simulate the effect of household practices on energy consumption based on the theoretical framework (See Figure 1), focusing on the comprehension of the take back effect and demand side flexibility. Bearing this in mind, this paper proposes a methodology to answer the following questions: (1)How do household practices and demand side flexibility affect heating-related energy consumption in the imposed retrofitted measures in social housing? (2)Can activity-based modelling (A-BM) predict heating-related energy consumption in imposed retrofitted social housing?. In order to answer these questions the following energy demand modelling framework in a spatial and societal contexts is proposed (See Figure 2).

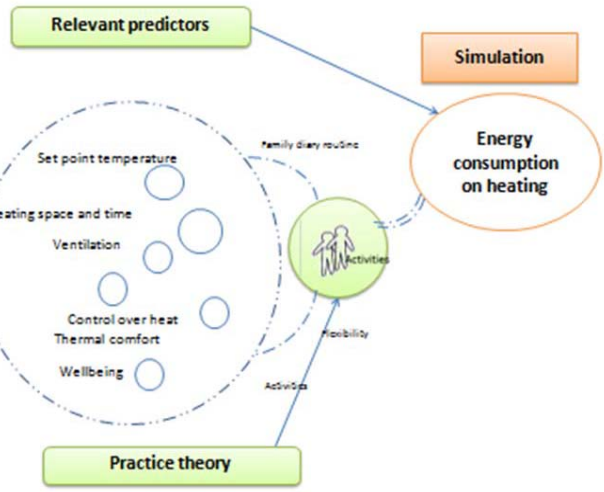


**Figure 1** Theoretical framework.

[2] A project is defined as a coordinated set of activities (Axhausen, K.W. (1998) 'Can we ever obtain the data we would like to have', *Theoretical foundations of travel choice modeling*, pp. 305-323., 1998)

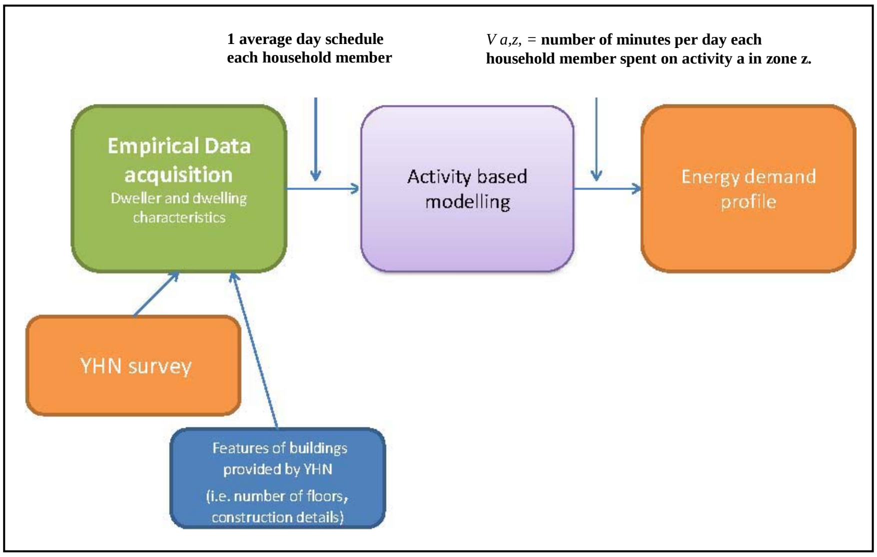


**Figure 2** Energy demand modelling framework

### 4.1 Empirical data acquisition

The aims of empirical data acquisition are to improve comprehension of how residents consume energy through household practices and produce initial parameters for the simulation of the energy demand. Thus, it is proposed that the empirical data for the simulation will be collected by means of a survey which will be specifically designed to produce specific data in a given location and with a specific target group. A quantitative survey has been chosen as the method for collecting 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 analyzing data.

The survey will be carried out in Newcastle upon Tyne, UK, where bottom up information will be collected from social housing to model energy demand as part of an on-going project between Your Homes Newcastle (an organization which is 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, taking into account that is expected that each flat is occupied by two people on average.

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 in using a questionnaire. The first section principally is related to respondent characteristics, for example, people living in home year-round, household composition (Live alone, couple, couple and children, etc) and household income. The second section will include a list of factors which according to previous studies have been perceived as improvement after solid wall retrofitting, such as level of warmth, draught, noise, happiness, external appearance and level of health related to cold diseases. Furthermore, the last section 'activities' the responders will be asked to complete a daily diary, in which they have to indicate their daily practices and routines at home on an average winter day. This part of the survey will be completed in a paper questionnaire. Activities have been classified into five main topics: basic needs, work/school activities, household obligations, entertainment and others. To take an example, entertainment activities 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 analyze similarities and differences between adopters and non-adopters of energy efficiency measures.

This 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 received the intervention yet. Only similar dwellings and dwellers will be considered, i.e. social housings 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 likely buildings to be surveyed are two buildings which received solid wall insulation and double glazing during the past two years, and the other two buildings are expected to have solid wall insulation installed during the course of the next year. Likewise, it is expected that tenants will have a similar social status, gender distribution and employment status (for example retired people). See summary of methodology control on 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 dwellers at the same period.

A pilot study will first be conducted with 10 households, in order to examine the practicalities and appropriate structure of the questions (e.g. average duration of an interview, language, target group) and, thus, refine the written questionnaires. Data will be collected by interviewers managed by YHN, using paper questionnaires for the dairy schedules and an e/Tablet-based survey to gather the remaining information. Finally, the study will run in January, 2014 and members of the households will be the unit of measurement for analysis. The decision as to whosoever answers the questionnaire, and who is the most qualified, will be left for householders to decide.

## 4.2 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 the energy demands on the domestic sector at micro level. The conceptual model interacts with an activity based model (interaction will be described on the sections 4.2.1 and 4.2.2). The methodological approach is described in Figure 3, which shows the model input, model process and model output.

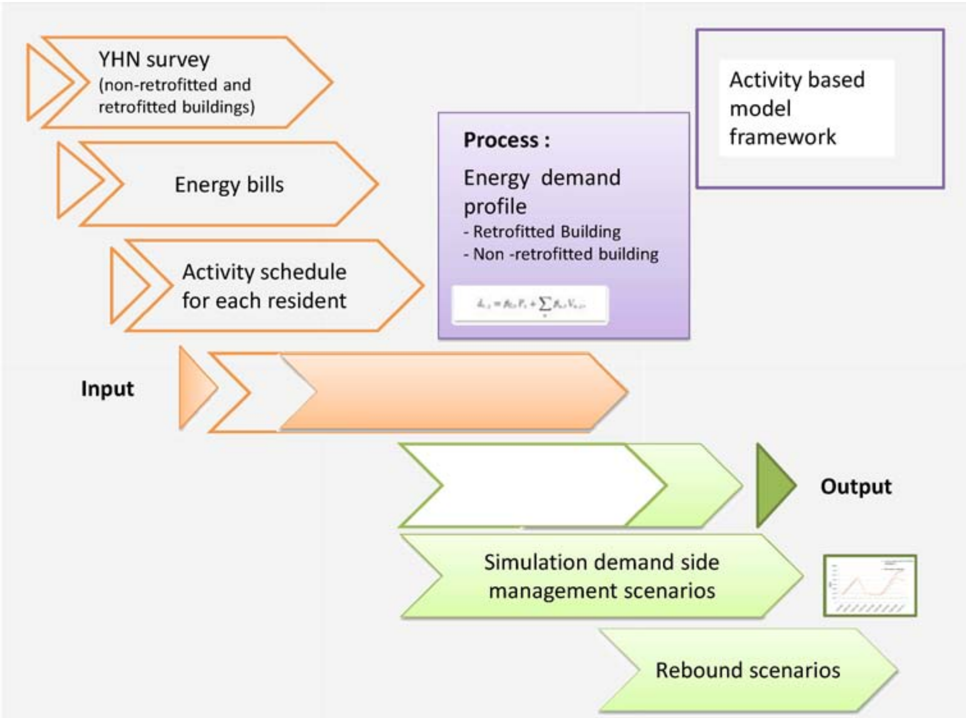


**Figure 3** Methodological approach

### 4.2.1 Model input

Firstly, it is intended to calculate the energy demand in a spatial and societal context using the idea of an activity based model (described in section 3.3), it is essential to establish that the following parameters (inputs) are not necessarily part of the current software functionalities –TASHA– developed by Miller and Roorda (2003) to model urban transport models. It is intended to adapt this software for the purposes indicated on this paper. Having said this, it is important to define how to represent the location of cases that will be simulated, in other words, the different residents will be assigned to four zones dependant to the location of their current buildings.

In addition, as was mentioned in the section 4.1 the survey 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.

Broadly speaking each member's daily activity schedule drawn from the survey will be codified to transform into a “txt extension file”, for example activity (e.g. shower=1), start time (e.g. 7:00 AM=10) and duration (e.g. 15 min=15) and number of adults (e.g. 1). Furthermore, Socio demographic characteristics such as age, gender, employment status and education will be also generated from observed patterns in the survey data.

### 4.2.2 Model process

This section explores how to convert activity schedules (inputs) into energy demands. It is expected that with the help of TASHA, episodes for these schedules will be drawn up, creating a file which contains different activities performed per day in minutes in a zone z, and its discrete frequency distributions. For example, for each activity (the number of times an activity is performed per day), activity duration (the likely duration of an activity for a given start time) and start times (the likely start time of an activity distributions) and the activity frequency for different combinations of activity purpose (meal preparation, working at home, sleeping etc.) will be created. Specifically this study case has to show activity types such as shower, cooking, cleaning in the zones (n=1 to 4, depending on the assignation of the building to each zone), start time and duration (min) for a determined population (for example n=180).

As first approach, the estimation of energy demand can be calculated following the method used to draw the energy in London by Keirstead and Sivakumar (2012).The formulation of the model was based on: $d_{r,z} = \beta_{0,r} P_z + \sum \beta_{a,r} V_{a,z}$ where $d_{r,z}$ = annual average daily demand for resource r in zone z; $P_z$ = observed population of each zone z, $V_{a,z}$ = the number of minutes per day spent on activity a in zone z and $\beta_{x,r}$ = the regression coefficients for resource *r*. (Ibid)

Calibration of the model will rely upon 1.5 years energy demand data obtained from electricity bills. Data of this type, however, is not publicly available, therefore, it is expected that permits will be obtained from the residents to gain access to the different providers such as for example, British Gas, E.ON, Scottish Power and other local or small providers of energy. As was mentioned previously, this method is a first approach, which will be evaluated on the basis of their limitations, since it is not sensitive to temperature changes and it has to be assumed that in the following years energy demand will increase it (Keirstead and Sivakumar, 2012), given that it is a regression model. By contrast, it is a simpler method which allows for focusing on practices at home.

In addition, although, the previous calculation considers energy demand activities which are mainly a function of the household members' daily schedule such as when a dweller member is taking a shower or watching TV, calculation of energy demand also has to include “passive” energy consumed by non-stop devices, such as for example the use of a freezer or modem (internet), which are switched every day. Indeed, it is quite relevant since the building heating system in this case study uses the tariff economy 7 (which for example means that these buildings use electricity to store up heat in the storage heaters, and if they are heated up at night, the heat is released during the daytime). Therefore, energy consumption is completely provided by a source of electricity and split gas and electricity demand is not possible. In addition, as was mentioned in the previous paragraph, space heating also depends on the climate and features of the house (type, size and insulation of the house).

Furthermore, it is necessary to establish the effect of energy demand on shared activities (for example the household members watching TV) and overlapping activities (for example activities taking place at the same time, such as washing the clothes, taking a shower and cooking). Finally, the energy practices that will be considered in the model prediction will be based on the winter energy consumption, therefore some practices and its equivalent energy demands might appear to be overestimated or underestimated compared with the average annual consumption.

### 4.2.3 Output

As was proposed in section 4, this model intends to answer the following questions, How do household practices and demand side flexibility affect heating-related energy consumption in the imposed retrofitted measures in social housing?. As can be seen, the characteristics of the case study, whereby energy is entirely supplied by electricity, makes it very difficult to differentiate electricity used for space heating from 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 will 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 time saver. The 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 hypothetical scenario, the projected energy demand generated by time saver activities decreases generating a saving of energy (KWh). In addition, practices such as changing the duration of shower, cleaning, switching off lights or shifting activities to off-peak hours can be also modeled.

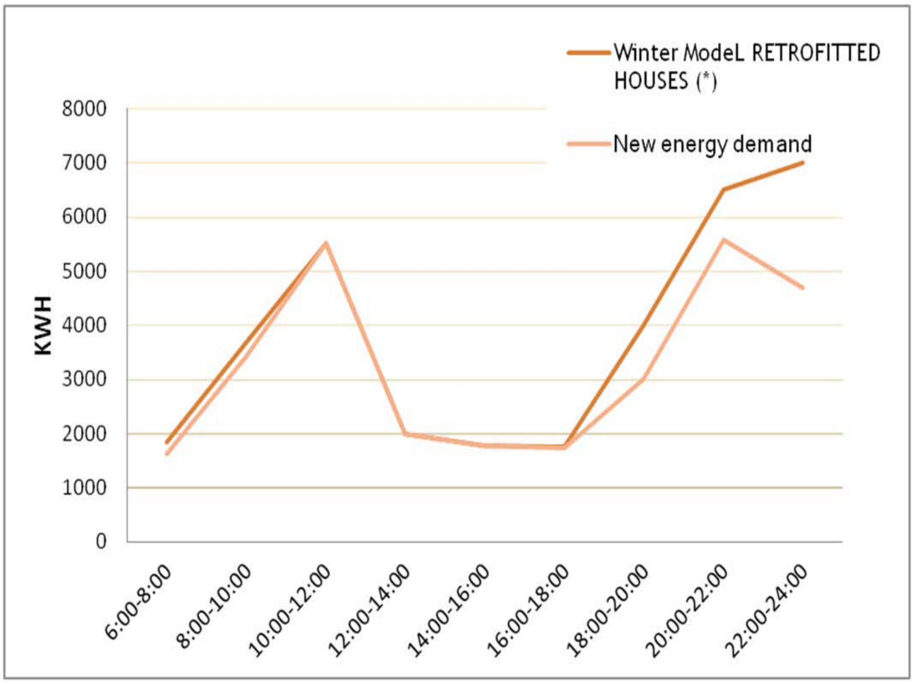


**Figure 4** Comparison of energy demand model business as usual v/s projected time saver energy model for a retrofitted house

In addition, the rebound effect will be revised taking into account the difference between the energy demands (See Figure 4) and their practices on both groups (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. Therefore, a possible scenario is shown in Figure 5.

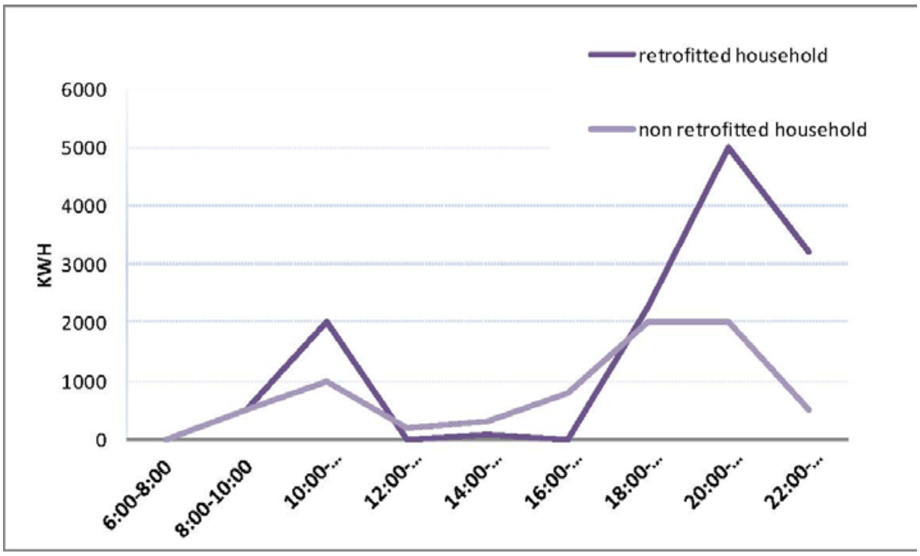


**Figure 5** Comparison of non-retrofitted and retrofitted household energy demand

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 6).

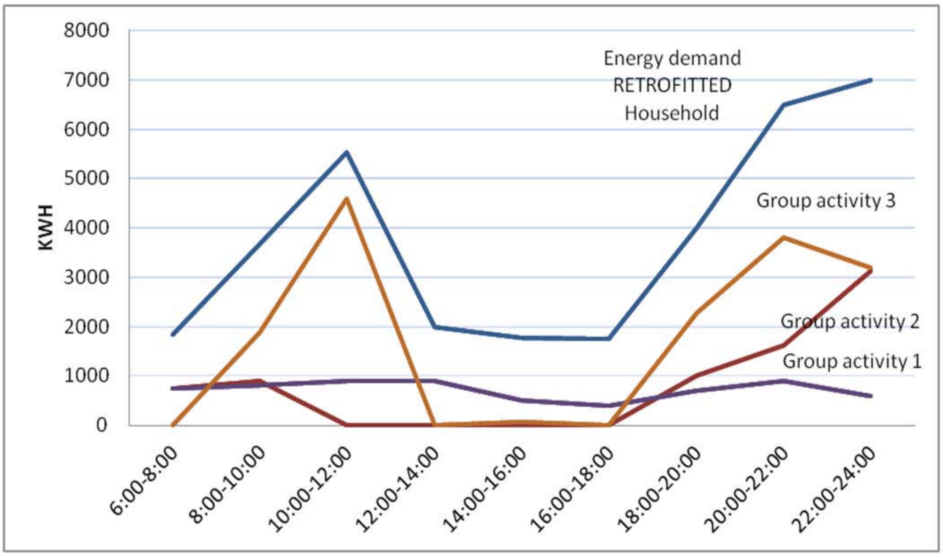


**Figure 6** Energy demand divided by household group activities (retrofitted building).

# 5 Conclusion

This paper has sought to deal with the new challenges of the energy demand model, proposing a highly disaggregated bottom up approach. The local commitments made at the “EU Covenant of Mayors” to reduce carbon emissions by 20% by 2020 (Newcastle City Council, 2010) and the UK low carbon agenda have to led an improvement of the energy efficiency measures of the existing stock through retrofitting schemes such as solid wall insulation. However, improvements may not be achieve the estimated reductions in energy demand, because of the take back effect.

Therefore, this paper has proposed to carry out a study to develop a better understanding of how household practices and demand side flexibility affect heating-related energy consumption. Thus, a revision of the proposed methodology for understanding the impact of rebound effect and “demand side flexibility” on energy demand using a case study in Newcastle upon Tyne has been undertaken. The modelling framework for this case study is based on the activity-based model framework, which had been previously used in the modelling of urban transport systems. It was 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.

Broadly speaking, the main outcome of this research study will be the modelling of the energy demand at residential level in a spatial and societal context based on the activity types and their duration. In turn, it can be used to evaluate "What-if" scenarios in demand-side management i.e. adjusting practices such as cleaning or washing. This also allows for analysis of the rebound effect by means of the difference between practices. Limitations and current 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 features of the house and weather conditions and counting of shared and overlapping activities (for example the household members watching tv) have also been covered.

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