



Predicting the diversity of internal temperatures from the English residential sector using panel methods

Scott Kelly^{a,b,e,*}, Michelle Shipworth^b, David Shipworth^b, Michael Gentry^c, Andrew Wright^d, Michael Pollitt^e, Doug Crawford-Brown^a, Kevin Lomas^f

^a Centre for Climate Change Mitigation Research (4CMR), University of Cambridge, 19 Silver St, Cambridge CB39EP, UK

^b UCL Energy Institute, University College London, Gower Street, London WC1E 6BT, UK

^c Global Action Plan, 9–13 Kean Street, London WC2B 4AY, UK

^d Institute of Energy and Sustainable Development, DeMontfort University, Leicester LE19BH, UK

^e Electricity Policy Research Group (EPRG), University of Cambridge, Trumpington Street, Cambridge CB21AG, UK

^f Department of Civil and Building Engineering, Loughborough University, Loughborough LE113TU, UK

HIGHLIGHTS

- ▶ A new method is proposed incorporating behavioural, environmental and building efficiency variables to explain internal dwelling temperatures.
- ▶ It is the first time panel methods have been used to predict internal dwelling temperatures over time.
- ▶ The proposed method is able to explain 45% of the variance of internal temperature between heterogeneous dwellings.
- ▶ Results support qualitative research on the importance of social, cultural and psychological behaviour in determining internal dwelling temperatures.
- ▶ This method presents new opportunities to quantify the size of the direct rebound effect between heterogeneous dwellings.

ARTICLE INFO

Article history:

Received 26 February 2012

Received in revised form 2 August 2012

Accepted 10 August 2012

Available online 29 September 2012

Keywords:

Temperature
Behaviour
Buildings
Domestic
Energy demand
Rebound effect

ABSTRACT

In this paper, panel methods are applied in new and innovative ways to predict daily mean internal temperature demand across a heterogeneous domestic building stock over time. This research not only exploits a rich new dataset but presents new methodological insights and offers important linkages for connecting bottom-up building stock models to human behaviour. It represents the first time a panel model has been used to estimate the dynamics of internal temperature demand from the natural daily fluctuations of external temperature combined with important behavioural, socio-demographic and building efficiency variables. The model is able to predict internal temperatures across a heterogeneous building stock to within ~ 0.71 °C at 95% confidence and explain 45% of the variance of internal temperature between dwellings. The model confirms hypothesis from sociology and psychology that habitual behaviours are important drivers of home energy consumption. In addition, the model offers the possibility to quantify take-back (direct rebound effect) owing to increased internal temperatures from the installation of energy efficiency measures. The presence of thermostats or thermostatic radiator valves (TRVs) are shown to reduce average internal temperatures, however, the use of an automatic timer is shown to be statistically insignificant. The number of occupants, household income and occupant age are all important factors that explain a quantifiable increase in internal temperature demand. Households with children or retired occupants are shown to have higher average internal temperatures than households who do not. As expected, building typology, building age, roof insulation thickness, wall U -value and the proportion of double glazing all have positive and statistically significant effects on daily mean internal temperature. In summary, the model can be either used to make statistical inferences about the importance of different factors for explaining internal temperatures or as a predictive tool. However, a key contribution of this research is the possibility to use this model to calibrate existing building stock

* Corresponding author at: Centre for Climate Change Mitigation Research (4CMR), University of Cambridge, 19 Silver St, Cambridge CB39EP, UK. Tel.: +44 (0) 7942 617 428 (M), +44 01223 764 867 (W).

E-mail addresses: sjk64@cam.ac.uk (S. Kelly), m.shipworth@ucl.ac.uk (M. Shipworth), d.shipworth@ucl.ac.uk (D. Shipworth), mig.gentry@gmail.com (M. Gentry), awright@dmu.ac.uk (A. Wright), m.pollitt@jbs.cam.ac.uk (M. Pollitt), djc77@cam.ac.uk (D. Crawford-Brown), k.j.lomas@lboro.ac.uk (K. Lomas).

for behaviour and socio-demographic effects leading to improved estimations of domestic energy demand.

© 2012 Published by Elsevier Ltd.

1. Introduction

1.1. Background

In the UK, the built environment accounts for approximately 40% of primary energy demand of which 60% is used for home heating, 20% for hot water and the remaining 20% for lighting and appliances [1]. In 2011 almost 90% of all UK dwellings used central heating systems as a primary heat source. Over the last sixty years a transition from individual room fires and heaters to more modern, controllable central heating systems has dramatically changed the way in which people use energy in their homes. Although modern gas central heating systems are arguably much more energy efficient, they also provide users with instantaneous heating¹ and thus create opportunities for increased energy consumption. This is for several reasons. First, they benefit from advanced controls and automation giving functionality and flexibility that are simply not available with more traditional heating methods. Secondly, little effort is required to increase consumption unlike traditional wood and coal fired heating systems. Finally, central heating has introduced the capability to heat every room in the house through dedicated radiators. As will be discussed, the repercussions of modern heating systems and controls on internal temperature profiles are still widely disputed. For example, Shipworth [2] shows there is no evidence that thermostat settings have changed between 1984 and 2007. Shipworth suggests that despite overall efficiency gains, the absence of a reduction in energy consumption may be explained by an increase in the total area of the dwelling now being heated, an increase in heating duration and an increase in the frequency of window openings to control temperature.

Because home heating contributes towards a significant component of total residential energy consumption, it is worthwhile scrutinizing the driving forces behind internal dwelling temperatures. A growing body of literature suggests that home heating is just as much due to the behavioural and social characteristics of people and how they interact with energy technology as it is to do with the physical properties and efficiency of the building [3–6]. The idea that people matter as much as buildings was pioneered by Lutzenhiser [7] where he argued that psychological, social, economic and behavioural aspects must be considered alongside the physical properties of the building. In his seminal paper Lutzenhiser coined this as the ‘cultural model’ of energy use. Following Lutzenhiser, Hitchcock [8] argued the need for a systems based framework, able to integrate the social and technical aspects of energy demand into a single model. In his analysis Hitchcock asserts that “energy consumption patterns are a complex technical and social phenomenon” and thus to be fully understood must be “viewed from both engineering and social science perspectives concurrently”. Although both authors made the intellectual leap to bring two very distinct research approaches together, many of the building stock models developed over the following several decades have never managed to fully incorporate these early ideas [9,10].

Since these early pioneers, most research has attempted to model and understand home energy demand through a deeper understanding of society (sociology) and human behaviour (psychology) [4,11–13]. Alternatively engineering models have attempted to build more accurate instrumentation and calculation

algorithms to improve the accuracy of modelling heating systems and heat loss through building envelopes [14–16]. Investigations in each research discipline have therefore grown in both scope and scale for the type of problems that can be considered, but neither has fully incorporated the beneficial advances made by other disciplines. Some authors, however, have started to develop bottom-up engineering models that utilise proxy variables to represent human behaviour. For example, Brown et al. [17] has developed a model utilising water consumption as a proxy for occupancy. Inroads have also been laid by Richardson et al. [18] where time of use surveys have been used to estimate occupancy patterns and domestic energy demand profiles of dwelling inhabitants. Although such studies provide a glimpse of what energy profiles might look like at the individual building level, such information has never been combined and integrated within a national building stock model requiring much larger samples from a heterogeneous building stock. Even today there is still no well defined path for incorporating human behaviour in bottom-up engineering building stock models. This assertion is supported by Audenaert et al. [19] who claims there is a clear gap in understanding the different behavioural factors that lead to an occupant's demand for heating, and calls for more research that identifies these driving factors.

The importance of behavioural and social factors is highlighted in a study by Gill et al. [13] where it is found that behaviour accounts for 51%, 37% and 11% of the variance in heat, electricity and water consumption respectively across different dwellings. Implicitly this suggests that models neglecting human behaviour misrepresent the estimation of home energy consumption by as much as $\pm 50\%$. However, the majority of residential stock models do not take social and behavioural factors into consideration. Top down models neglect behavioural factors, simply because it is not possible to aggregate dwelling level behaviour into any meaningful aggregate statistic for the entire building stock. On the other hand, bottom-up models are dominated by engineering building physics models that only consider the physical properties of the building envelope and the efficiency of the heating system. In both modelling approaches generalisations are made about the internal temperatures of dwellings. In top-down methods, internal temperatures are used to calibrate model estimates and adjust estimated energy consumption to match aggregate demand [20]. In bottom-up methods internal temperature is generally assumed constant across multiple dwellings or similarly adjusted as a function of the physical properties of the building ignoring completely the effect that different behaviours may have on energy use (BREDEM² [21]). Both approaches therefore neglect human behaviour and therefore fail to capture the decisions of individuals known to affect heating profiles and mean internal temperatures.

Contrary to popular belief, Shipworth et al. [22] show that heating controls may not reduce average living room temperatures or the duration of operation. Regulations, policies and programmes that assume the addition of controls will reduce energy consumption may therefore need to be revised. The impact that smart meters will have on reducing energy and emissions is also controversial. Darby [23] maintains there is little evidence to suggest that smart meters will automatically lead to a dramatic reduction in energy demand. Instead she calls for increased focus on overall demand reduction (rather than peak electricity demand reduction), improvements to

¹ “Instantaneous heating” refers to the activation of the system, central heating systems still typically take approximately 30–90 min for a dwelling to reach set-point temperatures.

² Building Research Establishment Domestic Energy Model (BREDEM) is the foundational building model used for assessing domestic buildings in the UK. It is also used as the basic calculation methodology for SAP and RdSAP.

Download English Version:

<https://daneshyari.com/en/article/6694194>

Download Persian Version:

<https://daneshyari.com/article/6694194>

[Daneshyari.com](https://daneshyari.com)