Building and Environment 70 (2013) 298–305

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Heating patterns in English homes: Comparing results from a national survey against common model assumptions☆

Gesche M. Huebner [a,*], Megan McMichael [a,1], David Shipworth [a,2], Michelle Shipworth [a,3], Mathieu Durand-Daubin [b,4], Alex Summerfield [a]

[a] UCL Energy Institute, 14 Upper Woburn Place, London WC1H 0NN, UK
[b] EDF R&D, 1 Avenue du Général de Gaulle, 92 140 Clamart, France

ARTICLE INFO

Article history:
Received 19 June 2013
Received in revised form
20 August 2013
Accepted 22 August 2013

Keywords:
Heating patterns
Heating demand temperature
Heating duration
Occupancy schedules
Building stock models
BREDEM

ABSTRACT

Heating patterns and temperatures are among the most important determinants of English home energy use. Consequently, building stock models, widely used for informing UK energy policy, are highly sensitive to the assumptions they make on how occupants heat their homes. This study examined heating patterns in English living rooms and compared them to model assumptions. A time-series of winter spot temperature measurements was translated into statements of the heating system being on or off during weekdays and weekend days, and the heating demand temperature estimated. The analysis showed that weekdays and weekend days are far more similar than commonly assumed. Contrary to model assumptions, homes were frequently heated outside assumed heating hours and not all homes were heated at the same time or followed the same pattern. The estimated demand temperature was about 20.6 °C, and the average temperature during heating periods was about 19.5 °C, both lower than the commonly assumed 21 °C used in models. Significantly, variability between homes in demand temperature and hours of heating was substantial. The results indicate the need to revisit some assumptions made in building stock models, and to take account of variability between homes when aiming at predicting space heating demand for an individual home.

1. Introduction

The Climate Change Act 2008 committed the UK to reducing its greenhouse gas emissions by 80% by 2050 from a 1990 baseline [1]. In order to achieve this, carbon emissions from UK homes will need to be near zero by that time. In order to reach that goal, the UK has set an intermediate goal of reducing emissions from homes by 29% by 2020 based on 2008 levels [2]. Energy use in homes makes up just under a third of total energy use in the UK, and within a home, approximately 57% of energy use is attributable to space heating [3].

Modelling energy consumption is a widely used method of understanding how much energy is used in the UK housing stock, the outputs of which provides a benchmark for making recommendations on energy saving policies and programmes, thereby reducing greenhouse gas emissions. In the UK, a widely used model for predicting home energy consumption is the Building Research Establishment Domestic Energy Model (BREDEM) that is consistent with the BS EN ISO 13790 standard. This is a data-driven building physics model which has a core space heating equation based on gains from heating systems and other elements (i.e. heating water, cooking, lighting, appliances) balanced against heat losses through the building fabric [4]. In BREDEM, space heating calculations are based on heat losses, gains and temperatures inside the dwelling [5]. Internal temperatures are calculated in two zones: the living area and the rest of the dwelling. The default assumption in the model is that the whole dwelling is heated only during specific time periods, and that the living area is heated to a higher temperature (usually of 3 °C) than the rest of a home during these periods [4]:

- Heating demand temperature in the living room: 21 °C
- Heating period weekday: 7:00 to 9:00 and 16:00 to 23:00
- Heating period weekend: 7:00 to 23:00

* Corresponding author. Tel.: +44 (0)20 3108 9129.
E-mail addresses: g.huebner@ucl.ac.uk (G.M. Huebner), m.mcmichael@ucl.ac.uk (M. McMichael), d.shipworth@ucl.ac.uk (D. Shipworth), m.shipworth@ucl.ac.uk (M. Shipworth), mathieu.durand-daubin@edf.fr (M. Durand-Daubin), a.summerfield@ucl.ac.uk (A. Summerfield).
1 Tel.: +44 (0)20 3108 5980.
2 Tel.: +44 (0)20 3108 5998.
3 Tel.: +44 (0)20 3108 5991.
4 Tel.: +33 1 47 65 49 06.

0360-1323/$ – see front matter © 2013 The Authors. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.buildenv.2013.08.028

Outside these specified time periods, the heating system is assumed to be off. It is understood that a single temperature and heating pattern are “idealised” in order to reflect assumed “standard heating regimes” to estimate energy consumption on a monthly (BREDEM 8) or yearly (BREDEM 12) basis ([4], p.7). However, the validity of some of the assumptions of these models is questionable and not sufficiently based on robust data [6,7].

It is important that BREDEM reflects reality as closely as possible as it is a foundation for many other UK building stock models (e.g. BREHOMES, The Cambridge Housing Model, DeCARB, UKDCM and CDEM [7]) and a current simplified BREDEM version (BREDEM 9) forms the basis for the Standard Assessment Procedure (SAP), the UK Government’s primary assessment mechanism for determining energy efficiency of homes. The BREDEM family of models serves a variety of purposes. As part of regulatory instruments, like the SAP, they set standards for energy use against which individual dwelling design proposals are evaluated for compliance. In doing this, they serve a normative function representing how the fabric and heating technology in dwellings should perform; they standardize occupant influences in order to assess the building performance independently of occupant effects. When used as the basis for building stock modelling, however, their purpose is to indicate how homes (i.e. occupied houses) actually perform. In this function they should correctly represent occupant influences in order to correctly estimate national energy demand from the nation’s homes. There is relatively little evidence from national UK studies comparable to BREDEM default values to assess whether they accurately reflect reality, either on average, or for individual homes.

Kelly demonstrated that estimates of energy demand made using SAP have been shown to be poor predictors of actual energy consumption [8]. Shipworth et al. found that the average maximum internal temperature for three winter months, used as a proxy for thermostat settings, was 21.1 °C, in line with the heating demand temperatures as assumed by BREDEM based models, but finding great variability between homes [9]. The variability echoes the findings of earlier studies: Hunt and Gidman’s large UK study in 1978 [10] and Palmborg’s small Stockholm study in 1981 [11].

The analysis of Shipworth et al. estimated a heating duration of 8.2 h on weekdays and 8.4 h on weekends, again with large variability between homes. This is substantially different to the BREDEM standard assumption of 16 h of heating for a weekend day but roughly in line weekday assumptions. Even the 1996 English House Condition Survey found regularly heated living rooms were *reportedly* heated for an average of 12.2 h per weekday, 13.5 h per weekend day, each with a standard deviation of 6.4 h [12]. A recent study of 59 homes that had received insulation upgrades found daily heating periods varied from 2 to 20 h [13]. None of these studies explicitly examined whether the temporal pattern of heating over the day coincided with the heating periods as assumed in BREDEM default values. Analysis of the 1996 English House Condition Survey found 36% of households heated their living rooms intermittently and 35% heated them all day during the week, with 45% heating them all day at the weekend [12]. In addition, almost half of households with central heating heated their living rooms intermittently, whereas almost half of households with a retiree heated their living rooms all day.

In a previous paper, internal temperatures were compared against BREDEM default values [14]. The analysis showed that temperatures in the assumed heating periods were significantly lower than the 21 °C assumed by BREDEM. However, the analysis only focused on comparing measured temperatures to the assumed temperature and did not consider the actual heating patterns of living rooms.

The heating patterns that are built into BREDEM indicate assumptions of when heating systems are ‘on’ or ‘off’. In order to test these assumptions, we have developed an algorithm that translates temperature sequences into statements about the heating system being ‘on’ or ‘off’ and applied this to temperature data from living rooms in English homes during winter. We compare our findings against the time windows of heating assumed in BREDEM. Further, we estimate the ‘heating demand temperature’ when the heating is ‘on’.

2. Methods

2.1. Survey and temperature measurements

The data analysed in this paper are derived from the Carbon Reduction in Buildings Home Energy Survey (CaRB HES), the first national survey exclusively focused on energy use in English homes, that commenced in early 2007 (for details, see Ref. [9]). Households were selected by stratified random sample drawn from the Postcode Address File. Sampling and face-to-face interviews in 427 homes were carried out by the National Centre for Social Research (NatCen). During the interview, householders answered questions on the building characteristics of their home, heating practices, and socio-demographics. For a subset of homes, temperatures were monitored in the bedroom and living room from mid July 2007 to early February 2008. HOBO UA 001-08 sensors are self-contained data loggers that recorded spot temperature every 45 min, resulting in 32 measurements per day. These sensors have a manufacturer reported accuracy of ±0.47 °C at 25 °C, and were placed in the home by the interviewer and/or the homeowner with instructions on correct placement, i.e. between knee and head height, away from any heat sources or direct sunlight. Calibration measurements were taken of each sensor in a climate chamber at 25 °C before placement in the home and used to correct the readings after the logged data had been extracted. The calibration error from all sensors was found to be minimal with an average error of $M_{\text{error}} = 0.19$ °C ($SD = 0.11$).

2.2. Sample characteristics

Of the 275 dwellings with data on living room temperatures, 11 used night-storage heaters, and 16 used other types of non-central heating technology; they were excluded from the following analysis as BREDEM assumptions differ for those technologies [4]. Of the remaining 248 homes, 93.5% had central heating with gas or LPG, and the other 6.5% had some other sort of central heating. For 119 dwellings, the existence of additional forms of heating for the main living room was reported, 125 did not use other heating in the main living room, and for four homes the data is missing.

A comparison of the CaRB data sample to the English House Condition Survey [15] showed an over-representation of owner-occupied and detached homes and bungalows, and an under-representation of privately rented accommodation and flats. Overall, the CaRB sample is largely similar to national estimates; for a more detailed comparison, see Ref. [14].

2.3. Temperature data and data cleaning

For this paper, the analysis focused on living room data in the winter months. Winter was defined as a 92-day period between November 2007 and January 2008, after which point the temperature loggers were withdrawn. A variable expressing average daily external temperature was created based on minimum and maximum temperature at local weather stations within the respondent’s Government Office Regions [16]. For no day or region in the data analyses for this paper did the maximum external temperature exceed 15.5 °C; due to the natural elevation of internal temperatures above external due to incidental gains, above this