Energy and Buildings 66 (2013) 688–696

Contents lists available at ScienceDirect

Energy and Buildings

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

The reality of English living rooms – A comparison of internal temperatures 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 26 March 2013
Received in revised form 18 June 2013
Accepted 7 July 2013

Keywords:
BREDEM
Building stock models
Heating demand temperature
Heating duration
Internal temperature
Variability

ABSTRACT

Objective: This study examines the extent that temperatures in English living rooms correspond to standard assumptions made in established UK building stock models.
Methods: Spot temperature measurements taken every 45 min over 92 winter days in 248 homes in England were analyzed and compared to the assumed thermostat setting of 21 °C inside and outside the assumed heating periods.
Results: Homes on average displayed lower internal temperatures during assumed heating periods and significantly shorter durations of heating to 21 °C than common models assume, with about 20% of homes never reaching the assumed demand temperature of 21 °C. Data showed a difference of only about 45 min in the duration of temperatures at or above the demand temperature for weekdays and weekends, contrary to the assumed difference of 7 h. Variability between homes was large.
Conclusion: These findings suggest that currently used standard assumptions of heating demand and heating duration do not accurately reflect the living room temperatures of dwellings in England.
Practice implications: Standard assumptions might have to be revised, in particular regarding the weekday–weekend differentiation. The prediction of internal temperature for a given home contains potential large error when using standard assumptions.

1. Introduction

In order to meet climate change and energy policy goals, the United Kingdom must reduce greenhouse gas emissions by 80% by 2050 from 1990 base line levels [1]. Since home energy use accounts for 23% of these emissions [2], the UK Government established a goal of reducing emissions from homes by 29% by 2020 [3]. Reducing energy consumption and emissions from residential homes requires understanding of both the buildings and the way they are used, since it is the two together that results in energy consumption. One common approach is to use models to predict home energy use, and then make recommendations for energy saving based on the outputs of the models. However, scarce empirical evidence is available to support the assumptions used in these models regarding occupant demand temperatures in UK dwellings.

Residential energy consumption models are largely grouped into either top-down models, which estimate consumption based on aggregated input parameters, or bottom-up models, which calculate consumption based on household-level variables and can then be extrapolated to a larger scale, such as the whole building stock for a country [4]. Bottom-up models can be useful for identifying specific energy-efficient and cost-effective measures for emissions reductions [5]. A widely used bottom-up model on which many housing stock models are based in the UK is the Building Research Establishment Domestic Energy Model (BREDEM). This is a data-driven building physics model which uses "heat balance equations and empirical relationships" to estimate energy demand, though the distinction between modelled parameters and the basis for empirical relationships remains uncertain [5, p. 1685]. This model was developed in the 1980s and has undergone a number of revisions of fine-tuning, particularly as it moved from a paper-based to computer-based tool [6]. The current versions estimate annual energy demand (BREDEM 12) and monthly energy demand

* Corresponding author. Tel.: +44 020 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.: +44 020 3108 5980.
[2] Tel.: +44 020 3108 5988.
[3] Tel.: +44 020 3108 5991.
[4] Tel.: +33 1 47 65 49 06.

0378-7788/$ – see front matter © 2013 The Authors. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.07.025

(BREDEM 8) of homes, and a modified version (BREDEM 9) forms the basis the Standard Assessment Procedure (SAP), the UK government's primary assessment mechanism for determining the energy efficiency of homes. The results of SAP inform, inter alia, the UK Building Regulations which instruct the building industry and set the expected standard for energy efficiency in homes. Many UK housing stock models use BREDEM as the foundation for calculating energy consumption of the domestic stock including BREHOMES, The Cambridge Housing Model, DeCARB, UKDCM and CDEM [5].

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.

BREDEM (and SAP) include a wide array of input parameters, including building materials, size and type of dwelling, heat loss, ventilation, lighting and appliance use, and water and space heating. Overall energy use is estimated from four main areas: space heating, water heating, cooking and lights and appliances. Of those four, space heating is the largest contributor to energy consumption; on average, it accounts for 57% of energy use in a home [3]. In BREDEM, space heating calculations are based on "heat losses, heat gains and the internal temperatures" in dwellings [7, p. 52]. Heat losses can occur due to the nature of building materials as well as through ventilation. Heat gains are calculated from heating systems, as well as other sources such as cooking, water heating, solar gains, gains from electronic devices, and metabolic gains. Internal temperatures are calculated in two zones: the living area (or living room) and the rest of the dwelling. The default assumption in the model is that the living area is heated to a higher temperature (usually 3 °C) than the rest of a home and only heated during specific time periods, specifically:

- Heating demand temperature (i.e. the thermostat setting): 21 °C
- Heating pattern:
  - o Weekday: 7:00–9:00, 16:00–23:00 (9 hours)
  - o Weekend: 7:00–23:00 (16 hours)

Outside this specified time periods, the heating system is assumed to be off. BREDEM based models assume that the demand temperature is reached immediately when the heating is on.

Heating systems and heating controls are also taken into account regarding these estimations. BREDEM assumes that the average temperature demanded in a living room is 21 °C only if it has central heating and a room thermostat; otherwise, the living room demand temperature is assumed to be slightly higher. A sensitivity analysis on a BREDEM-informed model, CDEM, found that heating demand temperature was the most important input variable, followed by heating pattern [8]. Hence, in order to predict energy consumption and carbon emissions correctly as energy efficiency measures are applied in the building stock, detailed estimates are needed from empirical measurements of heating demand temperatures and patterns.

The input parameters to BREDEM are based on empirical data and can be altered to include actual data from a given building. However, the default values which are commonly used for occupant-related variables, such as heating patterns or internal temperatures, have questionable validity: Oreszczyn and Lowe [9] indicate that more data is needed to validate the BREDEM model and capture the observed variations in occupant behaviour known to occur in the stock (see also [5,10]). In addition, Kelly demonstrated that estimates of energy demand made using SAP have been shown to be poor predictors of actual energy consumption [11], and more specifically, of the fuel consumption related to space heating [12].

Whilst 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, the analysis revealed large variability in the heating demand temperature [10]. Also, for weekends, the estimated heating duration was only 8.4 h, almost half of the BREDEM assumption of 16 h. For weekdays, the estimate was about in line with the length of time that BREDEM assumes for weekdays, i.e. 9 h. However, the authors did not analyze *when* the heating was on over the course of a day.

The aim of this paper is to test if the BREDEM default values for heating demand temperatures and heating duration accurately reflect living room temperatures in English homes. The data consists of living room temperatures recorded in 2007–2008 in 248 dwellings across the UK. The measured temperatures are compared to the BREDEM demand heating temperature of 21 °C and according to the default BREDEM heating pattern for weekdays and weekends. The investigation specifically examines the extent that the measured temperatures correspond with the assumed heating (and non-heating) periods in BREDEM, i.e. the temporal distribution of temperatures of 21 °C over the course of a day are examined. It is important to note that this approach only compares realized temperatures against assumed temperatures; the findings should not be interpreted as an indication of alternative heating durations and demand temperatures to be used in BREDEM models. This is because BREDEM assumes that the heating system can elevate internal temperatures to 21 °C the instant that temperature is demanded, and thus the duration of heating demand temperature being reached, and the duration of the heating being on, are identical. In reality, homes do not reach the demand temperature instantly, and so the duration of heating demand temperature being reached, and the duration of the heating being on, are not identical.

2. Methods

2.1. Survey and temperature measurements

This study draws on living room temperature data from the Carbon Reduction in Buildings Home Energy Survey (CaRB HES), the first national survey to exclusively focus on energy use in English homes, that commenced in early 2007 (for details, see [10]). 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 were used; these are self-contained data loggers that were programmed to record spot temperature every 45 min, resulting in 32 measurements per day. These 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. The sensors have a manufacturer reported accuracy of ±0.47 °C, however calibration measurements were taken for each logger before placement in the home and used to correct subsequent readings after the recorded data had been extracted.