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Central heating settings in low energy social housing in the United Kingdom

Adorkor Bruce-Konuah*, Rory V. Jones, Alba Fuertes, Pieter de Wilde

Department of Architecture and Built Environment, University of Plymouth, Drake Circus, Plymouth, Devon, PL4 8AA, UK

Abstract

This paper presents essential empirical data on heating setpoint temperatures and durations from UK social housing built to low energy standards. The data was derived from living room air temperature measurements. There were single, double and multiple heating periods per day in the dwellings with mean setpoint temperatures of 20.9°C and 21.0°C on weekdays and weekends respectively. The weekday mean heating duration was 8.4 hours and for weekends, it was 9.1 hours. The results could be used to better inform the assumptions of space heating behaviour used in energy models in order to more accurately predict the space heating energy demands of dwellings.

Keywords: Heating setpoint temperature; Heating periods; Heating durations; Low energy social housing

1. Introduction

In 2016 the energy used in UK domestic buildings accounted for 29% of total final energy consumption and 70% of this was used for space heating. Nearly 90% of homes are heated with a gas-fired central heating system [1]. Domestic space heating accounts for 11% of the country's carbon emissions. Reducing emissions from homes, and in particular those associated with space heating will be a key step towards achieving the legally binding carbon reduction target of 80% by 2050 compared to 1990 levels. Consequently, in recent times, understanding occupant

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* Corresponding author. Tel.: +44 01752 585173; Fax: +44 01752 585155.
E-mail address: adorkor.bruce@plymouth.ac.uk

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space heating behaviours has been a focus of attention for the UK research community and a detailed review of previous studies was presented by Wei et al. [2].

The energy consumption of UK dwellings is commonly predicted using energy models based on the Building Research Establishment Domestic Energy Model (BREDEM) [3]. The predicted energy demand for space heating is derived based on a standardized temperature profile, which assumes that the living room is heated to 21°C for 9 hours on weekdays and 16 hours on weekends. Previous studies have shown that predictions of a dwelling's energy demand are particularly sensitive to the setpoint temperature and the heating duration used in the modelling [4, 5]. In their sensitivity analysis, using an energy and carbon model of the English housing stock, Firth et al. [4] estimated that a 1% rise in heating setpoint temperatures would cause a 1.55% increase in CO_2 emissions, making setpoint temperature the most significant factor influencing space heating energy use. Heating duration was the second most significant influencing factor; a 1% increase in number of heating hours was estimated to result in a 0.62% increase in CO_2 emissions.

Despite the important roles that heating setpoint temperature and duration have on space heating energy demand, the models used to predict domestic energy demand, and hence inform carbon-reduction policy options, are based on standardized heating patterns which have been shown to misrepresent the variability of heating setpoint temperatures and durations in real homes [6–12]. Shipworth et al. [6] suggested that there was a need for updated and additional data to provide an alternative to the commonly used BREDEM model. In their review, they showed that there was little in the way of empirical data underpinning the building energy model. This lack of robust underpinning data undermines the credibility of recommendations generated for policy-making and scenario-planning processes.

Wei et al. [2] identified no less than 27 factors potentially influence a household's space heating settings and categorized these as: environmental factors, building and system factors, occupant related factors and other factors (e.g. contextual factors). However, they found that only five factors within these categories are commonly considered when modelling a building's space heating energy demand. All of the factors identified could result in variations in heating setpoint temperatures and heating durations.

This paper presents empirical data on heating settings, i.e. heating periods, setpoint temperatures and durations, which were derived from eight low energy social houses. These characteristics of space heating behaviour are derived from indoor air temperatures recorded in the living rooms of the dwellings. The results are compared to the assumptions used in BREDEM to determine the applicability and/or reliability of the assumptions.

2. Methodology

This paper uses indoor air temperature measurements collected, from six flats (Code for Sustainable Homes (CfSH) Level 4) and two houses (CfSH Level 5) built to low energy performance standards to determine their heating settings: heating periods, setpoint temperatures and heating durations. The dwellings are located on a housing estate in Torquay, UK.

2.1. The dwellings

An in-depth description of the structural characteristics of the dwellings is presented by Jones et al. [13]. The CfSH [14] was a voluntary national standard for the sustainable design and construction of new homes. The code assesses individual dwellings on nine categories (including energy and CO_2 emissions, pollution and health and wellbeing) and rates them on a scale from Level 1 to 6. Levels 4 and 5 relate to a 44% and 100% improvement over the 2006 Building Regulation Standards. All the dwellings are equipped with a gas central heating system where the heating periods and duration are controlled by a programmer/timer and the setpoint temperature is controlled by a central thermostat located in the corridor as well as thermostatic radiator valves (TRVs) attached to radiators in individual zones.

2.2. Data collection

As part of a larger Post-Occupancy Evaluation (POE) to assess the operational performance of the dwellings, calibrated HWM Radio-Tech Ecosense internal loggers (Accuracy: ±0.3°C; Measurement range: -20°C - 65°C) were used to record indoor air temperatures in the living rooms of the dwellings. As well as this, outdoor air temperature was collected from a meteorological station (Accuracy: ±0.3°C; Measurement range: -40°C - 75°C) setup on the housing estate where the dwellings are located. Temperatures were recorded at 10 minute intervals from 28 October 2013 to 02 November 2014 (371 days). The loggers were placed away from heat sources and direct sunlight.

2.3. Identifying the heating season

Outdoor temperature was used to identify the period when the dwellings were most likely to be heated. As the meteorological station was located onsite, it was assumed that throughout the study, all the homes experienced the same weather conditions as measured. Huebner et al. [7] have suggested that when average daily outdoor temperature is above 15.5°C, heating is not necessary due to the natural elevation of indoor temperature caused by solar heat gains. This temperature limit is also the base temperature used to calculate heating degree days for most buildings in the UK [15]. This criteria was used to identify the heating season in this study.

2.4. Identifying the heating periods and heating durations

The active central heating times were estimated from the recorded living room indoor air temperatures. Active central heating use was defined by Shipworth et al. [6] as times when the heating system is supplying heat to the dwelling. Huebner et al.'s [7] method for identifying heating periods was applied in this study. The temperatures recorded in this study were translated into statements regarding whether the heating system was on. If the magnitude of change in temperatures in 30 minutes was at least 0.3°C, it was considered as a change in the state of the heating system, from off to on. This temperature difference accounts for the occasional times of high solar gains or high internal heat gains. All the days in the identified heating season were considered in the analysis. Based on the approach derived by Kane et al. [9], the start of a regular heating period was assumed to be the first hour for which the temperature increase was at least 0.3°C for 10% or more days of the whole heating season. The end time of the regular heating period was determined as the hour for which the temperature increase of 0.3°C or more was less than 10% of the heating season days. At times where the heating was on for less than 10% of the days, it was assumed to be a manual override of the regular heating period or an increase in temperature due to other heat sources (Fig. 1).

2.5. Identifying the heating setpoint temperatures

As defined by Shipworth et al. [6], the thermostat setpoint temperature is the maximum temperature reached when the heating is active. This is because the thermostat is designed to turn the central heating boiler off when the room air temperature reaches the selected thermostat setting. In this study, the maximum temperature occurring in each heating period was taken as the setpoint temperature.

3. Results

The period from 01 November 2013 to 30 April 2014 (179 days: 129 weekday and 52 weekend days) was identified as the heating season, i.e. where the dwelling's heating system is used to increase the indoor temperature conditions. During this period, average daily outdoor air temperature ranged from 3.6°C to 14.3°C with an average of 8.5°C. Comparing the daily outdoor temperature profile and the daily indoor temperature profile, there was usually a mismatch between the peak outdoor temperature and peak indoor temperature, indicating that a rise in outdoor temperature does not necessarily cause a rise in indoor temperature.

From the temperature measurements, there were evident variations in the profiles in the dwellings. Some of the profiles were typical of the clusters (i.e. ‘two peak’ and ‘steady rise’) identified from a sample of 275 living rooms in English homes over three winter months [8]. The most common profile closely represented the assumptions used in BREDEM - two peaks, one in the morning and one in the afternoon/evening. This was seen in four out of the eight dwellings. In two of the dwellings, the profile was that of a ‘steady rise’ where the temperature increases steadily from late morning. In the remaining two dwellings, there were three peaks in the temperature profiles.

Heating profiles were developed for each dwelling using the method described in Section 2.4. The profiles were used to estimate the regular heating periods in the dwellings. Figure 1 is an example of the heating profile in one of the dwellings for weekdays (left) and weekends (right). The red lines on the graphs represent the 10% limit used to establish regular heating periods. On both weekdays and weekends, there was no heating between 00:00 and 06:00. On weekdays, there were three regular heating periods (06:30 to 07:30, 09:00 to 12:00 and 17:30 to 19:30) and at weekends, there were two regular heating periods (08:30 to 12:30 and 16:30 to 20:00). The profiles also show that for this dwelling not all days were heated during the heating season.

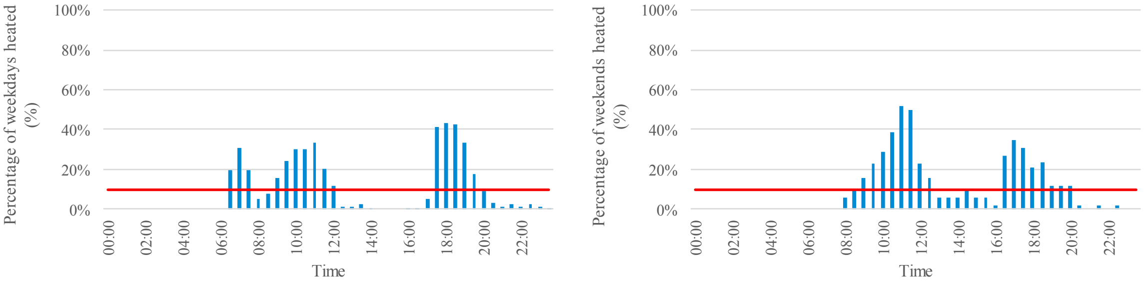

Fig. 1. Estimated daily heating profiles for one of the dwellings on weekdays (left) and weekends (right)

Table 1 presents the estimated weekday and weekend heating settings. The results showed that setpoint temperatures varied from one heating period to the next within the same day. Setpoint temperatures were lower in the first heating periods of the day and increased in the following heating periods. The average setpoint temperature was 20.9°C on weekdays and 21.0°C on weekends. There were also variations in the length of heating periods for weekday and weekend heating days. The estimated durations were shorter in the first heating periods of the day compared to the following periods.

Table 1. Thermal conditions and estimated heating settings

Days	Variables	Min	Max	Mean	SD
Weekdays (n = 129 days)	Number of heating periods	1	3	2.1	0.8
	Setpoint temperature (°C)	19.0	22.7	20.9	1.3
	Heating duration per day (hours)	4.0	11.5	8.4	2.2
Weekends (n = 52 days)	Number of heating periods	2	3	2.6	0.5
	Setpoint temperature (°C)	19.1	22.7	21.0	1.4
	Heating duration per day (hours)	5.5	12.0	9.1	2.2

4. Discussion

Overall, there were variations in number of heating periods per day, setpoint temperatures and durations among the sample of dwellings. Number of heating periods varied between weekday and weekend heating days. There were more multiple heating periods at weekends than there were for weekdays. The mean reported heating setpoint temperatures (20.9°C on weekdays and 21.0°C on weekends) are consistent with the 21°C recommended by the

WHO [16] as a comfortable indoor temperature to prevent health effects and also with the BREDEM assumption of 21°C used for energy modelling. The values are also similar to those estimated from measured indoor temperatures in previous studies: Kane et al. [9] reported a mean setpoint temperature of 20.9°C, Huebner et al. [8, 12] reported 20.6°C and Shipworth et al. [6] reported 21.1°C. This is a noteworthy level of agreement between findings, given the different samples. The previous study samples included dwellings with a range of performance standards (e.g. filled/unfilled cavity walls, SAP rating A – G). There is still some inconsistencies between respondent self-reported setpoint temperatures from surveys and estimated setpoint temperature from measurements: Jones et al. [11] reported a mean setpoint temperature of 20.9°C and Shipworth et al. [6] reported a much lower setpoint temperature of 19.0°C.

Similar to the results reported by Huebner et al. [7, 12] and Kane et al. [9], the temperatures reached in the first heating period are lower than those reached in the second and in some cases third heating periods. This could be because of the shorter heating durations; the first heating periods were the shortest and therefore it is possible that the heating may be turned off before the setpoint temperatures were reached. Although information on household occupancy patterns is missing in this study, the daily heating periods also give an indication of the households' occupancy patterns. The first and shorter heating period, occurring in the morning, is most likely to relate to the times between occupants waking up and leaving their homes. The longest heating periods were the last heating period of the day and these are likely to relate to the times between when occupants return home and when they go to bed. Using an assumption of 10% or more of heating season days to identify a regular heating pattern shows that on some days there may be a departure from the scheduled heating pattern. Occupants may manually turn the heating on for additional heating due to factors such as extreme low outdoor or indoor temperatures or household activities (e.g. drying laundry).

The mean weekday and weekend heating durations were 8.4 hours and 9.1 hours respectively. Shipworth et al. [6] using indoor temperature measurements previously reported weekday heating durations of 8.2 hours and weekend heating durations of 8.4 hours. In the same study, occupant self-reported heating durations were longer at 9.4 hours and 9.8 hours for weekdays and weekends respectively. Also from self-reported data, Jones et al. [11] reported slightly longer heating durations at 9.5 hours for weekdays and 11.2 hours for weekends. Kane et al. [9] estimated an average daily heating duration of 12.6 hours but did not report the difference between weekdays and weekends. The mean weekday heating duration obtained in the current study is quite similar to those reported in previous studies and what is specified in the BREDEM model for weekdays (9 hours). This indicates that on average households living in low energy dwellings heat their homes in a similar manner to other dwelling performance standards. This is unexpected as dwellings that are more thermally efficient are expected to have shorter heating durations compared to less efficient dwellings. This finding gives an indication of the rebound effect in social houses. This effect has been reported in a previous study of social housing that has undergone thermal upgrades as part of a retrofit process [17]. The mean weekend heating duration is also comparable to findings from earlier studies. However, similar to the results of previous studies, it is considerably lower than what is specified in the BREDEM model (16 hours), suggesting that BREDEM is overestimating weekend heating durations.

5. Conclusions

This paper provides an analysis of space heating settings in eight low energy social houses in the UK. Heating periods, setpoint temperatures and durations were estimated from indoor temperature measurements averaged over 30 minute intervals. The start and end of the heating periods were estimated from temperature differences, in order to calculate the heating durations. The maximum temperature recorded in the heating periods were taken as the setpoint temperatures.

The results from the study showed that heating settings varied among the dwellings. Double heating periods were the most common daily heating pattern, which is consistent with the general pattern assumed by BREDEM-based models often used for energy demand assessments in the UK.

There were no considerable differences between the heating settings (i.e. setpoint temperatures or heating durations) of the dwellings built to low energy performance standards reported in this study and dwellings with lower energy performance standards as reported in previous studies. This is concerning as heating durations would be expected to decrease in thermally efficient dwellings. The mean setpoint temperatures recorded in this study (weekdays: 20.9°C and weekends: 21.0°C) were consistent with the BREDEM assumptions and WHO recommendation (21°C). Overall, the mean reported weekday and weekend heating durations were 8.4 hours and 9.1 hours respectively. These values are also similar to results reported in earlier studies and confirm that BREDEM-based models significantly overestimate weekend heating durations. The results presented could be used to better inform the assumptions of heating settings used in energy models. It should be noted that the results presented in this paper are from a study of eight UK social dwellings and are therefore not representative of the wider housing stock. A larger scale study of low energy social dwellings would be a valuable extension to the current work.

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