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ScienceDirect

Energy Procedia 158 (2019) 3658–3663

Energy Procedia

www.elsevier.com/locate/procedia

10th International Conference on Applied Energy (ICAE2018), 22-25 August 2018, Hong Kong, China

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

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Abstract

This paper compares the central heating settings and the heating energy use performance of six flats and two houses built to low energy standards (Code for Sustainable Homes Levels 4 and 5) with a near identical flat and house built to minimum compliance only (2006 Building Regulations). As low energy houses are only recently emerging in the United Kingdom's social housing stock, and even fewer are subject to Post Occupancy Evaluation, little is known about their performance in terms of heating behaviour and energy demand. The results show that in general, the mean weekday and weekend setpoint temperatures, heating durations and heating energy use are lower in the low energy dwellings compared to the building regulations dwellings.

Keywords: Low energy social houses; Heating setpoint temperature; Heating durations; Heating energy use, Post Occupancy Evaluation

1. Introduction

The UK housing stock is responsible for over a quarter of the nation's final energy consumption and greenhouse gas (GHG) emissions. The 2008 Climate Change Act requires a 34% cut in 1990 GHG emissions by 2020 and an 80% cut by 2050. It will be impossible to meet these objectives without reducing emissions from the housing stock. In UK domestic buildings, the emissions primarily arise from the energy required for space heating. Nearly 90% of homes are heated with a gas-fired central heating system [1] and 70% of the household's energy demand is for space heating. Domestic space heating alone accounts for 11% of the country's carbon emissions.

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10.1016/j.egypro.2019.01.895

In the UK, between 2015 and 2016, energy consumption in the domestic sector increased by 3.1% with the majority of the increase being due to an increase in gas consumption [2]. In 2016, from the total amount of gas supplied to the domestic sector, 83.8% was used for space heating and the remainder was used for water heating (14.5%) and cooking (1.7%). Regarding space heating, previous studies have shown that predictions of a dwelling's energy demand are particularly sensitive to heating settings, i.e. setpoint temperature and heating duration, used in the modelling [3]. Firth et al. [3] estimated that a 1% rise in heating setpoint temperature can cause a 1.55% increase in CO_2 emissions and a 1% increase in number of heating hours can result in a 0.62% increase in CO_2 emissions.

Despite the significant role of setpoint temperature and heating duration on space heating demand, the models used to predict domestic energy demand are based on the same core building energy model – the Building Research Establishment's Domestic Energy Model (BREDEM) which assumes a standardized profile of heating settings for dwellings (living room is heated to 21°C for 9 hours on weekdays and for 16 hours on weekends) [4].

To tackle the emissions from housing, there has been significant upgrades of Part L1A of the Building Regulations (BR) with the aim of improving the energy performance of new build homes. In addition, a number of voluntary standards for the sustainable design and construction of new homes have also been prevalent. One such standard was the Code for Sustainable Homes (CfSH) which was revised in 2010. Although the standard was removed in July 2015, it is now expected to be incorporated into the mandatory Building Regulations.

This paper presents an analysis of the central heating settings, i.e. heating setpoint temperatures and heating durations and gas consumption in ten social houses: six flats and two houses built to low energy standards (CfSH, Levels 4 and 5) and a near identical flat and near identical house built to minimum compliance only (2006 Building Regulations).

2. Methodology

This paper uses indoor air temperature and gas consumption measurements collected, from seven near identical flats and three near identical houses, in terms of floor area, layout and building services, during their first winter season of occupation. The main variations between the dwellings were the standard to which they were constructed and their orientation. The flats and houses were located on a new-build housing estate in Torquay, a town in the South West of UK.

2.1. The dwellings

An in-depth description of the structural characteristics of the dwellings is presented by Jones et al. [5]. Table 1 presents a summary of the specifications of the dwellings investigated in this work. All the dwellings are equipped with a gas central heating system that is time and temperature controlled using a timer/programmer, thermostat and thermostatic radiator valves (TRVs). The CfSH [6] Levels 4 and 5 relate to a 44% and 100% improvement in thermal efficiency (i.e. lower U-values, high air tightness, high levels of insulation and triple glazing) over the 2006 Building Regulation Standards. Hence, they are expected to have reduced heat loss through infiltration. As the CfSH dwellings exceed regulatory compliance, they could be regarded as 'low energy' dwellings. The BR dwellings therefore provide a minimum benchmark against which heating settings and heating energy demand of the CfSH dwellings can be compared.

Table 1. Specifications of the dwellings

Dwellings	Performance standard	Floor area (m^2)	Airtightness ($m^3/hr.m^2$)	Wall U-value (W/m^2k)	Window U-value (W/m^2k)	Main heating system
Flats 1-6	CfSH Level 4	80.5	2	0.10	1.20	Combination boiler 91% efficiency and gas saver
Flat 7	2006 BR	80.5	5	0.24	1.80	Combination boiler 91% efficiency and gas saver
Houses 1-2	CfSH Level 5	140	2	0.10	0.70	System boiler 90% efficiency
House 3	2006 BR	140	5	0.26	1.80	System boiler 90% efficiency

2.2. Data collection

As part of a larger Post-Occupancy Evaluation (POE) to assess the operational performance of the dwellings, an automated monitoring system was installed to capture gas use and indoor temperature data. Calibrated data loggers were used to record the air temperature in the living rooms and outdoor air temperature at 10 minute intervals. The gas data was collected using pulse output sensors connected to the dwellings' mains gas meter. The pulse output sensor counts the number of pulses from the meter, which relate to a certain amount of energy passing through the meter. For domestic meters each pulse corresponds to 1Wh (1000 pulses per kWh). Data was collected from 28 October 2013 to 02 November 2014 (371 days).

2.3. Identifying heating settings

An outdoor temperature limit of 15.5°C which is the base temperature used to calculate heating degree days for most buildings in the UK [7] was used to identify the heating season, i.e. the months where an increase in indoor temperature is due to the central heating system. The active central heating times as defined by Shipworth et al. [8] were estimated from the recorded living room indoor air temperatures. The indoor temperatures were translated into statements regarding whether the heating system was on based on Huebner et al.'s method [9]. A temperature increase of 0.3°C within 30 minutes was used as an indication of the heating being on. Based on the approach derived by Kane et al. [10], the start and end times of the daily regular heating periods were identified in order to estimate the heating duration. As defined by Shipworth et al. [8], 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.

2.4. Identifying heating energy use

Total gas consumption was estimated for the identified heating season. From the Energy Consumption in the UK data, in 2013/2014, 83.8% of total gas supplied to the domestic sector was used for space heating [11]. Using this percentage, the space heating energy proportion of gas consumption was calculated for each dwelling.

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.

Heating settings and heating energy demand were estimated for each dwelling using the methods described in Sections 2.3 and 2.4 respectively. Using temperature differences, daily heating profiles were estimated. The profiles demonstrate when temperature increases are due to the heating system supplying heat to the dwelling. As a significant proportion of gas supplied to dwellings is used for space heating, it can be assumed that the daily profile of gas consumption also gives an indication of the heating profile of the dwelling. For this reason, the daily gas consumption profile was used to verify the heating profile estimated from indoor air temperature. Figure 1 shows the estimated daily regular heating periods and the gas consumption profile for one of the dwellings. On both weekdays and weekends there was no heating and hence no gas consumption between 00:00 and 06:00. Regular heating periods start around 06:00 and this is verified by the steep rise in gas consumption at this time. On both the weekdays and weekends, the gas consumption is seen to follow the estimated heating profile in this dwelling.

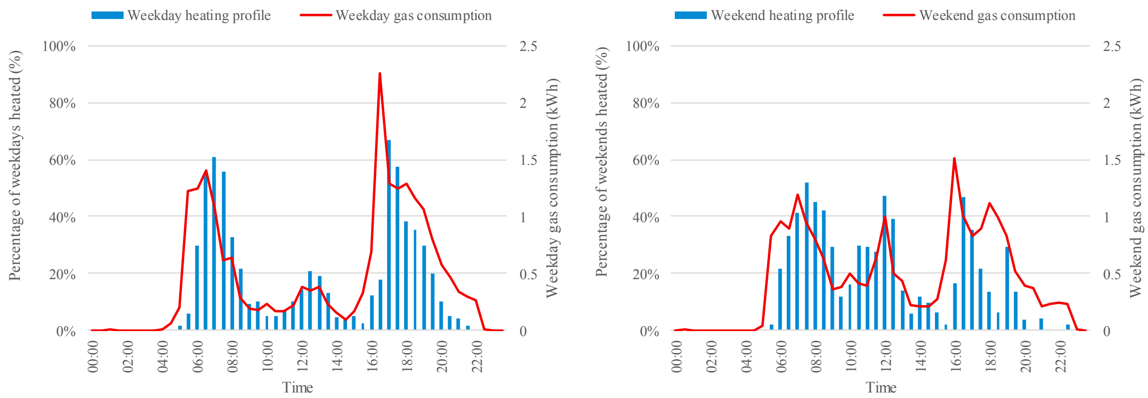

Fig. 1. Estimated daily heating profiles and gas consumption for one of the dwellings on weekdays (left) and weekends (right)

Table 2 presents the estimated mean weekday and weekend heating settings and the mean gas consumption (i.e. the heating energy consumption) during the heating season. There were variations in the heating settings and gas consumptions for both weekdays and weekends between the different dwelling performance standards.

Table 2. Mean estimated heating settings and heating energy use

Days	Heating settings and energy consumption	Flats 1-6 (CfSH 4)	Flat 7 (2006 BR)	Houses 1-2 (CfSH 5)	House 3 (2006 BR)
Weekdays (n = 129 days)	Mean setpoint temperature (°C)	20.9	22.2	20.8	22.8
	Mean daily heating duration (hours)	7.7	10.5	10.5	10.5
	Mean daily gas consumption (kWh)	9.0	18.2	30.7	62.3
Weekends (n = 52 days)	Mean setpoint temperature (°C)	21.1	23.2	21.0	22.2
	Mean heating duration per day (hours)	8.5	11.5	11.0	13.0
	Mean daily gas consumption (kWh)	10.1	18.3	34.0	54.8

In the CfSH flats, the mean setpoint temperatures was 20.9°C in the weekdays and 21.1°C in the weekends with mean heating durations of 7.7 hours in the weekdays and 8.5 in the weekends. In the BR flat, weekday and weekend setpoint temperatures were higher at 22.2°C and 23.2°C respectively and the heating durations were longer (10.5 hours and 11.5 hours). In the CfSH houses, the weekday and weekend mean setpoint temperatures were 20.8°C and 21.0°C and the durations were 10.5 hours and 11.0 hours and in the BR house, the setpoint temperatures were 22.8°C and 22.2°C with durations of 10.5 hours and 13.0 hours respectively.

Regarding gas consumption for heating during the identified heating season, the daily gas used in the CfSH flats ranged from 4.5kWh to 14.0kWh with an average of 9.6kWh over the weekdays and weekends. In the BR flat, average daily gas use was 18.3kWh. In the CfSH houses, gas use ranged from 28.9kWh to 35.9kWh with an average of 32.4kWh and in the BR house, the average was 58.5kWh over the weekdays and weekends.

4. Discussion

Overall, there were variations in the mean setpoint temperatures, heating durations and gas consumption between the CfSH dwellings and the 2006 BR dwellings. The setpoint temperatures in the CfSH flats were on average 1.7°C lower than in the BR flat and in the CfSH houses, they were on average 1.6°C lower than in the BR house. In the CfSH dwellings, the weekday (Flats: 20.9°C and Houses: 20.8°C) and weekend (Flat: 21.1°C and House: 21.0°C) setpoint temperatures are consistent with the 21°C recommended by the WHO as a comfortable indoor temperature to prevent health effects and also with the BREDEM assumptions used in energy modelling. The values are also similar to those estimated from measured indoor temperatures in previous studies [8 - 10]. The setpoint temperatures in the BR flat (weekday: 22.2°C and weekend: 23.2°C) and house (weekday: 22.8°C and weekend: 22.2°C) are higher than the values used in modelling for energy prediction and also higher than what has been reported in earlier work. These results suggest that occupants in the BR dwellings may need to heat their homes to slightly higher temperatures in order to be thermally comfortable. This may be a consequence of the lower thermal efficiency of their dwellings.

The shortest mean heating durations were recorded in the CfSH flats. The mean weekday and weekend heating durations in these flats (7.7 hours and 8.5 hours) were lower than the assumption used in BREDEM based-energy models (9 hours and 16 hours). This finding is expected due to the high thermal efficiency (i.e. low U-values and high airtightness), which ensures reduced heat loss through the building fabric. The mean heating durations on weekdays were identical in the CfSH houses and the BR flat and house and only marginally lower in the CfSH house than in the BR flat and house in the weekends. The weekday heating durations in these dwellings (10.5 hours) was higher than the BREDEM assumption but the weekend heating durations (BR Flat: 11.5 hours; CfSH houses: 11.0 hours; BR house: 13.0 hours) were lower implying that BREDEM may overestimate weekend heating durations of the UK housing stock, including dwellings specifically built to low energy performance standards.

The annual gas consumption of all the dwellings was reported by Jones et al. [12]. In general, the flats used less heating energy than the houses and this is because the floor area of the houses ($140m^2$) is almost twice that of the flats ($80.5m^2$). The CfSH flats used an average of 23% less gas than the BR flat and the CfSH houses used an average of 68.7% less gas than the BR house. In the BR flat, due to the low thermal efficiency of the building fabric, it will take longer to raise the indoor temperature to the setpoint temperature (as seen in the longer heating durations on both weekdays and weekends) hence more energy will be used to heat this flat. This observation was not evident in the houses, particularly on the weekdays where the mean heating durations were identical. However, the impact of the thermal efficiency of the fabric is observed. The CfSH house used significantly less energy for heating compared to the BR house. It is worth noting that the sample size, particularly for the houses is a limitation in this study. There were only two CfSH houses and only one BR house. Another limitation in this study is that actual household activities which can have an impact on gas consumption are also unknown, i.e. cooking activities and hot water demand. More data, including household activities from more houses are needed before a conclusion can be drawn on the differences between heating settings and heating energy use.

4. Conclusions

This paper provides an analysis of central heating settings and heating energy demand in eight low energy social rented dwellings (six flats and two houses) built to low energy performance standards (CfSH) and two social rented houses (one flat and one house) built to building regulation standards only. Daily heating profiles were identified from indoor air temperature measurements averaged over 30 minute intervals. The heating duration was estimated from the start and end times of the heating periods and the maximum temperatures recorded in the periods were taken as the setpoint temperatures. As it was assumed that an increase in the indoor air temperature during the identified season was due to the central heating providing heat to the dwelling, daily heating energy consumption was estimated from gas consumption measurements. The daily gas consumption profile was also used to validate the method used to identify the daily heating periods.

The results from the study showed that the weekday and weekend heating setpoint temperatures were lower in the CfSH dwellings compared to the BR dwellings. In the CfSH flats the weekday and weekend setpoint temperatures were 20.9°C and 21.1°C respectively and in the BR flat it was 22.2°C and 23.2°C. In the CfSH houses they were 20.8°C and 21.0°C and in the BR house it was 22.8°C and 22.2°C. The setpoint temperatures in the CfSH dwellings are consistent with the assumptions used in BREDEM based models but the setpoint temperatures in the BR dwellings are higher.

The results showed that heating durations also varied among the dwellings. The CfSH flats had the lowest heating durations on weekdays (7.7 hours) and weekends (8.5 hours) compared to the BR flat (weekday: 10.5 hours; weekends: 11.5 hours). This is expected as the CfSH standard is characterized by high thermal efficiency of the fabric. Although the weekday heating durations in the BR flat and house and also in the CfSH houses were higher than what is used in the energy models, the weekend heating hours were significantly lower. This indicates that the BREDEM based models used for predicting residential space heating energy overestimates the weekend heating durations even for dwellings built to low energy standards.

Overall, gas consumption was lower in the flats compared to the houses. This is expected as the flats are smaller than the houses. Also, gas consumption was lower in the CfSH dwellings compared to the BR dwellings. The CfSH dwellings are more airtight and will therefore maintain their setpoint temperatures for longer without having to turn the heating on, hence using less heating energy. It should be noted that the results presented in this paper are obtained from a study of ten UK dwellings and are therefore not representative of the wider housing stock. A larger scale study of UK social dwellings would be a valuable extension to the current work.

Acknowledgements

The authors would like to express gratitude to the anonymous housing association that provided access to the dwellings, as well as additional financial support for the monitoring equipment used.

References

[1] DECC, "United Kingdom housing energy fact file," London, 2013.
[2] BEIS, "Energy Consumption in the UK," London, 2017.
[3] S. K. Firth, K. J. Lomas, and A. J. Wright, "Targeting household energy-efficiency measures using sensitivity analysis," *Build. Res. Inf.*, vol. 38, no. 1, pp. 24–41, 2010.
[4] B. R. Anderson *et al.*, *BREDEM-8 Model Description: 2001 Update*. Building Research Establishment (BRE), Garston, and Department for Environment, Food and Rural Affairs (DEFRA), London, 2002.
[5] R. V. Jones, A. Fuertes, E. Gregori, and A. Giretti, "Stochastic behavioural models of occupants' main bedroom window operation for UK residential buildings," *Build. Environ.*, vol. 118, pp. 144–158, 2017.
[6] DCLG, "Code for Sustainable Homes: Technical Guide," *Department for Communities and Local Government*, 2010. [Online]. Available: http://www.planningportal.gov.uk/uploads/code_for_sustainable_homes_techguide.pdf. [Accessed: 13-Mar-2018].
[7] Carbon Trust, "Degree days for energy management," 2012. [Online]. Available: https://www.carbontrust.com/media/137002/ctg075-degree-days-for-energy-management.pdf. [Accessed: 06-Mar-2018].
[8] M. Shipworth, S. K. Firth, M. I. Gentry, A. J. Wright, D. T. Shipworth, and K. J. Lomas, "Central heating thermostat settings and timing: Building demographics," *Build. Res. Inf.*, vol. 38, no. 1, pp. 50–69, 2010.
[9] G. M. Huebner, M. McMichael, D. Shipworth, M. Shipworth, M. Durand-Daubin, and A. Summerfield, "Heating patterns in English homes: Comparing results from a national survey against common model assumptions," *Build. Environ.*, vol. 70, pp. 298–305, 2013.
[10] T. Kane, S. K. Firth, and K. J. Lomas, "How are UK homes heated? A city-wide, socio-technical survey and implications for energy modelling," *Energy Build.*, vol. 86, pp. 817–832, 2015.
[11] BEIS, "Energy Consumption in the UK - 2017 Data Tables." London, 2017.
[12] R. V. Jones, A. Fuertes, S. Goodhew, and P. De Wilde, "The Actual Performance of Aspiring Low Energy Social Houses in the United Kingdom," *Energy Procedia*, vol. 105, no. July 2015, pp. 2181–2186, 2017.