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2016-09-01

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http://hdl.handle.net/10026.1/4914

10.1016/j.enbuild.2016.06.006
Energy and Buildings
Elsevier

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Space heating preferences in UK social housing: A socio-technical household survey combined with building audits

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Abstract

This paper provides an analysis of the relationships between dwelling, household, and motivation, behaviour and perception characteristics and winter heating setpoint temperatures (n=111) and heating periods (n=148 and 145) used in UK social housing. The work capitalises on primary data from a socio-technical household survey, undertaken in Plymouth, UK, during 2015, which was merged with building audit data collected by the social housing association managing the properties. The mean reported heating setpoint temperature was 20.9°C and the average weekday and weekend day heating periods were 9.5h and 11.2h respectively. The results suggest that heating setpoint temperatures and periods vary greatly among UK social houses, but there are clear systematic variations according to dwelling, household, and motivation, behaviour and perception characteristics. The research could enable social housing providers, the government and commercial organisations to target energy efficiency measures (i.e. thermal upgrades) and social interventions (i.e. behaviour change) at those dwellings and households where their impact may be most beneficial. The results presented could also be used to better inform the assumptions of heating preferences in energy models, which could result in more realistic predictions of the space heating demands of social housing and the potential energy savings from refurbishment measures.

Keywords: Space heating preferences, Social housing, Socio-technical survey, Building audit, Heating setpoint temperature, Heating periods, Energy modelling

1. Introduction

Energy use in domestic buildings accounts for 29% of total UK energy consumption with around two thirds used for space heating [1]. Therefore, reducing heating energy use in housing is imperative if the UK is to achieve its commitment to reduce national carbon emissions by 80% of 1990 levels by 2050 [2]. In order to achieve these reductions, three key avenues exist, the refurbishment or replacement of the existing housing stock [3-5], decarbonisation of the domestic heating supply [6] and social interventions (behaviour change) to encourage more efficient use of energy [7-8].

In line with this commitment, the UK social housing sector in recent years has embarked on a large scale programme of thermal upgrades as well as the installation of more efficient heating systems and controls. A key funding mechanism for this work has been the Energy Company Obligation (ECO) [9], a government scheme which obligates large energy suppliers to deliver energy efficiency measures in domestic buildings, with a particular focus on low income and vulnerable households. However, the current £800m a year scheme will end in March 2017 and will be replaced with a 20% cheaper scheme [9]. A better understanding of the dwellings (e.g. type, age, number of habitable rooms, etc.) and households (size, composition, health status, etc.) for which energy efficiency measures would be most beneficial could therefore be helpful for targeting and delivering schemes, such as ECO, despite their marked budget reductions.

In addition, recent studies have shown that actual savings from the energy efficient refurbishment of existing houses is often less than predicted [10]. This is referred to as the energy performance gap [11-12]. Among the wide number of contributing factors to the energy performance gap, the 'rebound' or 'take-back' effect [13-14] is evident, in which dwelling occupants choose to heat their homes to higher temperatures or for longer after refurbishment rather than benefit from the potential energy savings. This effect may be particularly strong for the social housing sector as the occupants are likely to have low or fixed household incomes and may therefore currently choose to operate their homes at lower internal temperatures at the expense of their thermal comfort [15]. These lower internal temperatures are unlikely to be reflected in the modelled predictions of the energy savings from the installation of energy efficiency measures and as a result energy savings could be overestimated [16-21].

A number of recent studies have stated that there is little guidance regarding the heating setpoint value (i.e. the thermostat setting used by a household to control the heating system) and heating periods (i.e. the number of hours that the heating system is on) which should be used for energy modelling of domestic buildings [16-17]. Furthermore, standardised heating patterns underpinning Simplified Building Energy Models (SBEM), such as the Building Research Establishment Domestic Energy Model (BREDEM) [18] and BS EN ISO 13790 standard [19] have been shown to misrepresent the variability of heating setpoint values and periods found in real homes [20-24].

In addition, another recent UK study [25] identified that attitudinal variables, specifically, people's attitudes towards using less energy to save money and whether they believed reducing their heating use would affect their thermal comfort were related to heating setpoint temperatures and durations used at home. The results showed that attitudes helped explain heating temperatures and durations, even when dwelling and household characteristics were controlled.

This paper aims to provide a better understanding of the effects of dwelling (e.g. type, age, number of habitable rooms, etc.), household (e.g. size, composition, health status, etc.), and motivation, behaviour and perception characteristics (e.g. affordability of energy bills, perceived control over energy use, heating related behaviours, etc.) on the choice of heating setpoint temperatures and heating periods in UK social housing.

The work reported in this paper capitalises on primary data collected during a socio-technical household survey, undertaken in Plymouth, UK, during 2015, which was merged with building audit records held by the social housing association managing the dwellings.

Social housing represents 17.4% of the UK housing stock and is therefore a significant target for energy efficiency measures. However, previous studies exploring space heating preferences have primarily focussed on owner-occupied and privately rented dwellings [20-25]. The social housing sector is an interesting sample of the population as households are likely to have low or fixed household incomes and as a result are keenly aware of the cost of energy [26] as well as at increased risk of experiencing fuel poverty [27]. The heating preferences of social housing residents may therefore vary from those observed in previous studies addressing other tenure types.

The results presented in this paper could be used in energy models which may provide more realistic predictions of the space heating energy demands of new-build and existing social housing undergoing thermal upgrades. In addition, the analysis could enable social housing providers, the government and other commercial organisations to target energy efficiency measures (i.e. thermal upgrades) and social interventions (i.e. behaviour change) at those dwellings and households where their impact may be most beneficial.

2. Literature review

2.1. Factors affecting household space heating preferences

Past literature has identified key factors that influence households' space heating preferences in domestic buildings [15,20,24-25,28-62]. A detailed international review and discussion of these factors and methods is provided by Wei et al. [17]. In their review, the drivers of space heating preferences were categorised as:

(i) Environmental factors (outdoor climate [28-33], indoor relative humidity [34], outdoor relative humidity [33] and wind speed [33])
(ii) Building and system related factors (dwelling type [20,24,30,35-38], , dwelling age [30-31,39-40], dwelling size [30], room type [15,31,37,39,40-43], house insulation [24,29,44-46], type of heating system [32,39,47], type of heating control [24,35,40,42,48-51], type of heating fuel [30-31] and previous dwelling type [51])
(iii) Occupant related factors (age [15,40,46-47,51-57], gender [57], culture/race [30,59], education level [30,51], socio-economic classification [60], household size [15,42,46,54], household income [28,39,46,52,54], tenure [60-61], thermal sensation [46,60], perceived indoor air quality and noise [32] and health [46])
(iv) Other factors (time of day [28-30,35,37,42,46,52,62], time of week [42], occupancy [30,37,47,51,54,62], heating price [52,59], awareness of energy use [28,36,50] and attitudes about energy use [25])

The authors of the review found that no less than 27 factors potentially influence a household's space heating preferences, but at present, only 5 of the factors (outdoor climate, indoor relative humidity, occupancy, room type and time of day) are commonly considered when modelling a building's space heating demand and accordingly predicting potential energy savings from refurbishment.

2.2. Modelling household space heating preferences

Energy modelling is used to calculate the space heating energy demands of buildings and is based on a mathematical representation of a building's heat balance. The energy required to heat a building is dependent on the balance between six heat flows: heat from the heating system; heat transmission through the building's façade; external and internal heat gains; heat from ventilation and infiltration; and heat stored in or released from thermal mass. For domestic buildings, heat input from the heating system is related to the household's heating preferences: setpoint temperature (i.e. thermostat setting) and heating period (i.e. the period of time heating is on) as well as heat from ventilation.

In recent years, the representation of occupant behaviour in buildings has received increased research attention due to the significant influence it can have on the performance of buildings [63-66]. In relation to space heating preferences, studies have shown that predictions of a dwelling's energy demand are particularly sensitive to the heating setpoint temperature and the duration of heating used in the modelling [67-68]. However, as noted by Wei et al. [17], at present, there is little guidance regarding the heating setpoint values and periods that should be used.

Depending on which study is consulted, heating setpoint values and periods were typically chosen based on building standards [34], the researchers' personal experience/preference [69-72] or based on measured internal temperatures [73-74]. Although the latter method can help reduce the difference between assumed and actual setpoint values, this method has two main weaknesses, firstly, *"measured internal temperature is not the same as the setpoint due to effects such as overheating, intermittency, inertia, imperfect control"* [19], and secondly, longitudinal monitoring of internal temperature is often required to obtain reliable estimations of the setpoint temperature [17].

To further add to this issue, commonly used standardised heating patterns primarily underpinning Simplified Building Energy Models (SBEM), such as the Building Research Establishment Domestic Energy Model (BREDEM) [18], which is consistent with the BS EN ISO 13790 standard [19] have been shown to misrepresent the variability of heating setpoint values and periods found in real homes [20-24], thus questioning their reliability for predicting space heating demand in individual homes.

Table 1 provides examples of the heating setpoint temperatures and periods used in previous domestic energy modelling studies and standards. It can be seen that a wide range of heating setpoint values have previously been used for residential energy modelling (15-26°C). Furthermore, some researchers simulated multiple setpoint temperatures in their studies to account for variations in occupant behaviour [34,71,73-75,81-82,86,94]. Many of the studies used the same setpoint temperature for all building zones (e.g. living rooms, bedrooms, kitchens, etc.), although some varied this value [18-19,74,79-80,86-87,89-94]. In addition to assigning a setpoint temperature for heating periods, a number of studies also defined a setback temperature for non-heating periods [73,75-76,81,86-95]. In these cases, the heating will still come on during non-heating periods (normally unoccupied times or at night) if the internal temperature of the building falls below the setback temperature.

In relation to the heating periods used, in general, it was evident that studies defined the heating period according to the dwelling's expected occupation hours [18-19,73-74,81-82,86,88-94]. This is based on the assumption that occupants do not heat their homes when they are not at home. This assumption may well underestimate the heating periods of some homes, especially when a programmer is used to turn the heating on or off. In the study by Martinaitis et al. [86], the researchers added one additional hour to the heating period before occupants arrived home to account for this potential issue. The majority of studies reviewed were found to use the same heating periods for weekdays and weekend days, the exceptions to this were the BREDEM and BS EN ISO 13790 standards and the studies by Wei et al. [18-19,81-82]. All of the studies examined used either a single (24h or morning to evening) or double (morning and evening) heating pattern.

Table 1 Input values for heating setpoint temperature and periods used in previous domestic energy modelling studies

Study/standard (Country)	Heating setpoint/setback temperature(s) (°C) and building zones used in each model (M)	Weekday heating period(s) and duration (h) used in each model (M)	Weekend day heating period and duration (h) used in each model (M)
BREDEM / BS EN ISO 13790 [18-19] (UK / Europe)	M1. 21 (living rooms), 18 (bedrooms)	M1. 07:00-09:00 (2) and 16:00-23:00 (7)	M1. 07:00-23:00 (16h)
Fabi et al. [34] (Denmark)	M1. 21 (all zones) M2. 20 (all zones) M3. 18 (all zones)	-	-
Wall [69] (Sweden)	M1. 20-26 (all zones)	-	-
Thomsen et al. [70] (Belgium, Finland, Denmark, Canada, Germany, Netherlands)	M1. 20 (all zones)	-	-
Branco et al. [71] (Switzerland)	M1. 22.5 (all zones) M2. 20 (all zones)	-	-
Saitoh and Fujino [72] (Japan)	M1. 23 (all zones)	-	-
de Meester et al. [73] (Belgium)	M1. 20 / 16 (all zones) M2. 20 / 16 (all zones) M3. 21 (all zones) M4. 24 / 20 (all zones)	M1. 06:00-08:00 (2) and 16:00-00:00 (8) / 00:00-06:00 (6h) and 08:00-16:00 (8) M2. 06:00-00:00 (18) / 00:00-06:00 (6) M3. 00:00-00:00 (24) M4. 07:00-22:00 (15) / 22:00-07:00 (9)	M1, M2, M3, M4. Same as weekday

Love [74] (UK)	M1. 16 (living rooms) M2. 20 (living rooms, bedrooms and kitchen) M3. 23 (all zones)	M1. 07:00-08:00 (1) and 19:00-20:00 (1) M2. 07:00-09:00 (2) and 17:00-23:00 (6) M3. 00:00-00:00 (24)	M1, M2, M3. Same as weekday
Bonte et al. [75] (France)	M1. 18 / 17 (all zones) M2. 24 / 17 (all zones)	M1, M2. 08:00-19:00 (11)	M1, M2. Same as weekday
French thermal regulation (RT2012) [76] (France)	M1. 19 / 17 (all zones)	-	-
Mettetal [77] (France)	M1. 24 (all zones)	-	-
Tommerup et al. [78] (Denmark)	M1. 20 (all zones)	-	-
Bojic et al. [79] (Servia)	M1. 20 (living rooms, bedrooms and kitchen), 22˚C (bathrooms), 15˚C (hallways)	-	-
Wei et al. [80] (UK)	M1. 20 (living rooms and bedrooms), 18 (hallways and kitchen), 22 (bathroom)	M1. 00:00-00:00 (24)	M1. Same as weekday
Wei et al. [81] (UK)	M1. 22 (all zones) M2. 22 / 18 (all zones) M3. 22 / 18 (all zones)	M1. 00:00-00:00 (24) M2. 00:00-08:00 (8) and 18:00-00:00 (6) / 08:00-18:00 (10) M3. 07:00-23:00 (16) / 23:00-07:00 (8)	M1. 00:00-00:00 (24) M2. 00:00-00:00 (24) M3. 08:00-23:00 (15) / 23:00-08:00 (9)
Wei et al. [82] (UK)	M1. 21 (all zones) M2. 19.5 (all zones) M3. 18 (all zones)	M1, M2, M3. 07:00-09:00 (2) and 16:00-23:00 (7)	M1, M2, M3.07:00-23:00 (16)
Blight and Coley [83] [84] (UK)	M1. Average 21.56 (all zones)	-	-
Karlsson et al. [85] (Sweden)	M1. 23-26 (all zones)	-	-
Martinaitis et al. [86] (Lithuania)	M1. 22 / 19 (living rooms, bedrooms and kitchen), 23 / 20 (bathroom) M2. 22 / 18 (living rooms, bedrooms and kitchen), 23 / 19 (bathroom) M3. 20 / 18 (living rooms, bedrooms and kitchen), 21 / 19 (bathroom) M4. 20 (living rooms, bedrooms and kitchen), 21 (bathroom)	M1. 00:00-10:30 (10.5) and 17:00-00:00 (7) / 10:30-17:00 (6.5) M2. 00:00-08:30 (8.5) and 17:00-00:00 (7) / 08:30-17:00 (8.5) M3. 00:00-08:15 (8.25) and 17:30-00:00 (6.5) / 08:15-17:30 (9.25) M4. 00:00-09:30 (9.5), 11:30-15:30 (4) and 17:30-00:00 (6.5)	M1, M2, M3, M4. Same as weekday
Peeters et al. [87] (Belgium)	M1. 21 / 18 (living rooms, kitchen and hallways), 24 / 21 (bathroom), 15 (bedrooms)	-	-
Brum et al. [88] (USA)	M1. 21 / 17 (all zones)	M1. 08:00-12:00 (4) / 17:00-22:00 (5)	M1. Same as weekday
CIBSE [89,90,91] (UK)	M1. 22 / 15 (living rooms), 21 / 15 (bathroom), 20 / 15 (hallways), 19 / 15 (bedrooms and kitchen)	M1. 04:00-23:00 (19) / 23:00-04:00 (5)	M1. Same as weekday
DOE [92] / Hendron and Engebrecht [93] (USA)	M1. 21 / 12 (living rooms, kitchen and bathroom), 20 / 12 (bedrooms and hallways)	M1. 04:00-23:00 (19) / 23:00-04:00 (5)	M1. Same as weekday
Marini et al. [94] (UK)	M1. 22 / 15 (living rooms), 21 / 15 (bathroom), 20 / 15 (hallways), 19 / 15 (bedrooms and kitchen) M2. 21 / 12 (living rooms, kitchen and bathroom), 20 / 12 (bedrooms and hallways) M3. 18 (all zones) M4. 21 / 14 (living rooms), 20 / 14 (bathroom), 19 / 14 (hallways), 18 / 14 (bedrooms and kitchen) M5. 20 / 11 (living rooms, kitchen and bathroom), 19 / 11 (bedrooms and hallways)	M1. 04:00-23:00 (19) / 23:00-04:00 (5) M2. 04:00-23:00 (19) / 23:00-04:00 (5) M3. 05:45-22:30 (16.75) / 22:30-05:45 (7.25) M4. 05:45-22:30 (16.75) / 22:30-05:45 (7.25) M5. 05:45-22:30 (16.75) / 22:30-05:45 (7.25)	M1, M2, M3, M4, M5. Same as weekday
Good et al. [95] (UK)	M1. 18 / 16 (all zones)	-	-
Asaee et al. [96] (Canada)	M1. 21 (all zones)	-	-

3. Current study

This paper aims to provide a better understanding of the effects of dwelling (e.g. type, age, number of habitable rooms, etc.), household (e.g. size, composition, health status, etc.), and motivation, behaviour and perception characteristics (e.g. affordability of energy bills, perceived control over energy use, heating related behaviours, etc.) on the choice of heating setpoint temperatures and heating periods in UK social housing. This paper responds to a number of key gaps identified in the literature review. Firstly, key factors influencing households' space heating preferences in domestic buildings are identified. However, unlike previous studies which have focussed on owner-occupied and privately rented dwellings [20-25], this study targets a better understanding of heating preferences in social housing. The social housing sector is a unique sample of the population as households are likely to have low or fixed household incomes, be keenly aware of the cost of energy [26] as well as at increased risk of experiencing fuel poverty [27]. The heating preferences of social housing residents may therefore vary from those observed in previous studies addressing other tenure types. Secondly, as identified by Wei et al. [17], at present, there is little guidance regarding the heating setpoint values and periods that should be used for energy modelling of domestic buildings. This paper provides such values which could be used to obtain more realistic predictions of the space heating energy demands of new-build and existing social housing undergoing thermal upgrades. Thirdly, the analysis could enable social housing providers, the government and other commercial organisations to target energy efficiency measures (i.e. thermal upgrades) and social interventions (i.e. behaviour change) at those dwellings and households where their impact may be most beneficial.

4. Methods

4.1. Socio-technical household survey

The data analysed in this paper are derived from a socio-technical household survey undertaken as part of the European Horizon 2020 research project: Energy Game for Awareness of energy efficiency in social housing communities (EnerGAware) [97]. The survey was administered to 2,772 social houses (social rented and shared ownership) in the city of Plymouth, UK, which represents 12.6% of the city's social housing stock [98]. The households receiving the survey represented all of the social housing in Plymouth managed by housing association DCH (formerly Devon and Cornwall Housing), a partner of the project. Plymouth was the case study city chosen, as it is has one of the largest social housing stocks in the UK, accounting for 20.1% of the city's housing [98].

A self-report, paper-based survey, accompanied by a letter, a one-page flyer about the project and a pre-paid returning envelope was sent by post to the households on 18th May 2015. The letter invited households to either complete the paper-based survey and return it in the pre-paid returning envelope or undertake the survey online through the Internet survey software SurveyMonkey. A platinum version of the software was used to create a custom branded project survey. A further letter to remind households to complete the survey was sent out on the 1st June 2015. To encourage households to complete and return the survey, a prize draw was used as an incentive. All surveys received before the 25th June 2015 were entered into the prize draw to win one of ten prizes, including family days out in Plymouth and £50 shopping vouchers.

The survey took about 15 minutes to complete and contained 12 pages and 68 standardised closed questions. In total, 537 of the households completed the survey by the 25th June 2015 (504 paper-based and 33 online), giving an overall response rate of 19.4%.

The paper and Internet survey responses were input, cleaned and organised in an IBM SPSS Statistics 22 database. Two versions of the database were created, an anonymous version for wider public access and reuse and a confidential version with limited access for only those project partners requiring access to the confidential information.

The socio-technical household survey provided information for this paper about the household characteristics (e.g. Age of Household Representative Person (HRP) [1], household size and composition, highest qualification of HRP, welfare benefits status, health of HRP and disabled household members), motivation, behaviour and perception characteristics (e.g. Affordability of energy bills, worry about energy bills, understanding, consideration and perceived control of energy use at home, perceived ability to save energy at home, heating related behaviours and dwelling occupancy pattern), as well as reported winter heating setpoint temperature and winter weekday and weekend day heating periods.

4.2. Building audits

The data from the socio-technical household survey was merged with property records from the social housing association's asset management and building stock condition database. The data are collected and managed by an in-house professional team of building surveyors. A continuous process of carrying out building audits is maintained to ensure that property data is correct and up to date.

The dataset provides a comprehensive overview of the key structural elements and services in each home. It also contains the dataset for the RdSAP energy rating methodology which enables a Standard Assessment Procedure (SAP) rating to be calculated for the dwellings [99]. SAP is the UK government's national calculation methodology for the energy efficiency assessment of domestic buildings and is used to check compliance with building regulations in England and Wales for new (Part L1A) and existing buildings (Part L1B). It is also the methodology used for delivering the EU Energy Performance of Buildings Directive (EPBD) [100] and is used to produce energy performance certificates [101]. The RdSAP dataset and SAP ratings were undertaken by accredited Domestic Energy Assessors.

The social housing association's asset management and building stock condition database provided data for this paper about the dwelling characteristics (e.g. dwelling type and age, number of floors and habitable rooms, wall construction and insulation, roof construction and insulation thickness, window type and age, door type and age, heating system type and SAP rating).

4.3. Sample characteristics

This paper examines the heating preferences of a sub-sample of the 537 households, those which heated their homes with a gas-fired boiler and had a thermostat for defining the heating setpoint temperature. The data regarding the presence of heating controls in the dwellings were obtained from the housing association's asset management and building stock condition database. Gas-fired central heating systems are the focus of the current paper because they are installed in 91% of the UK housing stock [1].

Of the 537 households responding to the socio-technical household survey, 276 provided thermostat settings; however, 8 households provided thermostat settings that were not in the normal 10-30°C range marked on nearly all thermostats[2]. These were considered errors and were excluded from the analysis of reported thermostat settings. This data screening method is consistent with previous studies [25]. In the remaining sample of 268 homes, 111 had a gas-fired boiler with thermostatic control and were included in the analysis of heating setpoint temperatures. Furthermore, 383 of the survey respondents reported their weekday and 381 their weekend day heating periods. Of these,

[1] The Household Representative Person (HRP) is the individual that is taken to represent that household. In this study it describes the person that completed the survey.
[2] Reported thermostat settings of 4°C, 32.5°C, 35°C (3), 40°C (2) and 60°C were excluded from the analysis.

148 and 145 of the households respectively had a gas-fuelled boiler and were included in the analysis of heating periods (Table 2).

Table 2. Summary of study samples

<table>
<tr><td rowspan="3">Responded to the socio-technical household survey
n = 537
Initial sample</td><td>Provided thermostat settings
n = 276</td><td>Provided thermostat settings in the normal 10-30˚C range
n = 268</td><td>Gas-fired boiler with thermostatic control
n = 111
Heating setpoint temperature sample</td></tr>
<tr><td colspan="2">Provided weekday heating periods
n = 383</td><td>Gas-fired boiler with thermostatic control
n = 148
Weekday heating period sample</td></tr>
<tr><td colspan="2">Provided weekend day heating periods
n = 381</td><td>Gas-fired boiler with thermostatic control
n = 145
Weekend day heating period sample</td></tr>
</table>

A comparison of the social housing subsamples used in this paper with the composition of social housing at the national scale as reported in the 2013-14 English Housing Survey [102] is provided in Table 3. It can be seen that the study subsamples had an over-representation of terraced houses and lower proportions of all other dwelling types. The subsamples also over-represented smaller and middle-to-older age households. This is reflected in the higher proportion of households with HRPs that were either employed or retired amongst the subsamples. The percentages of unemployed, lone parent with dependent children and one person households, groups which are typically higher in social housing than private rented or owner occupied dwellings were, in general, representative of the national scale.

Table 3 Composition of the study subsamples compared to the 2013-14 English Housing Survey (EHS)

Characteristic	Heating setpoint temperature sample (%) n = 111	Weekday heating period sample (%) n =148	Weekend day heating period sample (%) n = 145	EHS, 2013-14 (%) n = 3,449 (social housing only)
Dwelling type				
Detached	0.0	0.0	0.0	1.2
Semi-detached	15.3	12.2	11.7	21.9
Terraced	49.5	52.7	53.1	32.3
Flat or maisonette	35.2	35.1	35.2	44.3
Household size				
1	46.8	51.4	51.0	40.9
2	32.4	32.4	33.1	26.2
3	12.6	8.8	8.3	14.9
4	4.5	4.7	4.8	10.4
5+	3.7	2.7	2.8	7.6
Age of HRP				
16-24	0.0	0.0	0.0	5.3
25-34	5.8	8.0	8.1	13.5
35-44	16.5	18.8	18.5	18.2
45-54	27.2	26.8	26.7	20.1
55-64	24.3	24.6	25.2	14.6
65-74	17.5	14.5	14.8	12.3
75+	8.7	7.3	6.7	16.0
Employment status of HRP				
Employed	45.7	46.2	45.7	36.7
Retired	34.8	31.1	31.1	29.6
Unemployed	9.8	15.1	15.5	8.6
Student	2.1	1.7	1.7	1.3
Other	7.6	5.9	6.0	23.8
Household composition				
Couple, no dependent children	26.0	30.2	30.8	17.5
Couple with dependent child(ren)	9.0	7.1	6.0	14.1
Lone parent with dependent child(ren)	20.0	17.4	17.9	17.3
Other multi-person household	4.0	3.5	3.6	10.3
One person	41.0	41.8	41.7	40.9

4.4. Reported winter setpoint temperatures and heating periods

The socio-technical household survey asked the households to state the temperature at which they normally set their thermostat during the winter. The respondents could specify a value in ˚C or tick one of two boxes indicating that they did not know what temperature they normally set their thermostat or that the question was not applicable (i.e. the dwelling did not have a thermostat). From the 111 dwellings with a gas-fired central heating system and thermostat, 13 respondents provided a range of temperatures rather than a single temperature (e.g. 20-22˚C). In these cases, the average of the two values was used in the analysis (i.e. 21˚C).

Participants were also asked when they normally have their heating on during a typical winter week day and weekend day. Respondents could specify at which times the heating came on and went off during the period of a day, up to a maximum of three sets of 'on-off' periods. In addition, a tick box was available to indicate if the heating was normally always on (i.e. 24 hours). Households were requested to input their start and end times of heating periods using a 24-hour clock method (e.g. 07:00-08:00), however where respondents used a 12-hour clock (e.g. 7am-8am), where possible, this was converted during data input. The start and end times of heating periods were then transformed into total heating hours for a weekday and weekend day for each household. The percentages of gas heated dwellings with one, two or three as well as 24 hour heating periods were computed.

The questions used to gather data about the winter heating setpoint temperatures and heating periods have previously been employed in a national [103] and city-scale (Leicester) [104] study of energy use in the UK, thus the current study maintains comparability with these existing UK studies. The previous studies however have primarily focussed on owner-occupied and privately rented dwellings (13.2% of the dwellings in the national-scale study were social housing), whereas the current study exclusively addresses social housing.

4.5. Data analysis

This paper provides an analysis of the variations in mean winter heating setpoint temperatures and heating durations according to dwelling, household and motivation, behaviour and perception characteristics. The analysis of mean winter setpoint temperatures highlights differences between groups and deviations from the World Health Organisation's (WHO) recommended indoor temperature of 21˚C, which is considered necessary to maintain a comfortable indoor environment and prevent potential health effects for the occupants [105]. The upper and lower 95% confidence intervals (95% CIs) for the data are also presented to demonstrate the distributions of setpoint temperatures reported, as well as the extreme values reported in the coldest and warmest homes and where the health effects may be most severe.

5. Results

5.1. Mean winter heating setpoint temperature

The mean reported winter heating setpoint temperature of the sample as a whole was 20.9˚C (SD = 3.3˚C), which is consistent with the 21˚C recommended by the WHO as a comfortable indoor temperature, and to prevent potential health effects. The thermostat settings reported by participants ranged from 12-30˚C[3].

Table 4 shows the variations in reported winter heating setpoint temperature in relation to dwelling, household, and motivation, behaviour and perception characteristics.

[3] Reported thermostat settings below 10˚C and above 30˚C were excluded from the analysis (see section 4.3)

Differences in the thermostat settings chosen by households were found according to the dwelling type and construction. Respondents living in semi-detached houses reported higher (M = 22.9, SD = 3.6) and those in semi-detached bungalows lower (M = 20.1, SD = 2.2) mean winter thermostat settings than respondents living in other dwelling types. Households residing in newer dwellings constructed after 2007 reported choosing much cooler winter setpoint temperatures (M = 19.3, SD = 4.6) than older dwellings. In fact, the lower 95% CI indicated that 5% of dwellings constructed after 2007 used thermostat settings of 15˚C or cooler. Whilst, similar mean thermostat settings were identified for dwellings with between two and four habitable rooms[4], occupants of dwellings with either five or six habitable rooms stated selecting higher thermostat settings (M = 22.9, SD = 4.5). Households living in dwellings with both filled (insulated) and unfilled (uninsulated) cavity walls (M = 21.6, SD = 3.1) had much warmer setpoint values than those that were timber frame (M = 19.8, SD = 3.0). The coldest 5% of timber frame dwellings had thermostat settings of 16.9˚C or less. Occupants residing in dwellings that had undergone thermal upgrades to the walls (i.e. cavity or solid wall insulation) (M = 21.7, SD = 3.2), chose greater temperatures than those in their as built condition (M = 20.2, SD = 3.3).

Whilst no clear relationship could be identified regarding the effects of multiple glazing on thermostat settings, due to only three homes in the sample being single glazed, the age of the windows installed appear to be related to the setpoint temperature selected. Households living in homes with either the oldest (1982-89: M = 22.6, SD = 5.6) or newest windows (2005-09: M = 22.0, SD = 2.6; 2010+: 22.2, SD = 4.4) reported having the highest setpoint temperature settings. This pattern was also evident in relation to the age of the back door (1970-89: 21.3, SD = 2.4; 2005+: 21.3, SD = 2.5). Dwellings with a front door installed between 1970 and 1989 also had higher reported thermostat settings (M = 22.6, SD = 4.5). Occupants of dwellings with a timber front door (M = 21.9, SD = 3.8) were also identified as having warmer setpoint values.

The heating system type installed had no relationship with thermostat setting. Households with either a combi or condensing combi boiler both reported a mean thermostat setting of 20.8˚C. Overall, the least efficient homes, dwellings with a SAP rating in the first quartile (0-25), were identified as having lower thermostat settings than higher efficiency properties (M = 20.2, SD = 1.7).

In relation to the household characteristics, differences in mean thermostat setting were identified between households of different ages, sizes, compositions, welfare benefit status and health.

The analysis found that households with a HRP between 50 and 59 (M = 22.2, SD = 3.7) and over 80 years old (M = 21.4, SD = 3.0) tended to have higher heating setpoint temperatures in their homes, whilst those with a HRP between 40 and 49 had lower (M = 19.8, SD = 3.2). Compared to other household sizes, three person households stated choosing cooler (M = 19.3, SD = 4.2) and two occupant households warmer thermostat settings at home (M = 21.3, SD = 3.7). It should be noted that the lower 95% CI for the mean thermostat setting of three person households was very cold at 16.9˚C. Single parent families with at least one child also reported particularly cold mean thermostat settings (M = 17.9, SD = 3.3) compared to other household compositions. The coldest 5% of dwellings occupied by single parent families, as indicated by the lower 95% CI, had heating setpoint temperatures of 14.8˚C or below.

Households in receipt of welfare benefits (M = 21.2, SD = 3.3) stated having heating setpoint temperatures that were on average 0.9˚C warmer than those not in receipt of benefits (M = 21.2, SD = 3.3).

[4] Habitable rooms include any living room, sitting room, dining room, bedroom, study or similar; and also a conservatory if it has an internal quality door between it and the dwelling. A kitchen/diner having a discrete seating area with a table and four chairs also counts as a habitable room. Excluded from the room count are any room used solely as a kitchen, utility room, bathroom, cloakroom, en-suite accommodation or similar; any hallway, stairs or landing; and also any room without a window.

Dwellings occupied by a HRP which considered their general health as very bad during the last 12 months, reported mean thermostat settings almost 2˚C colder (M = 20.1, SD = 4.3) than those rating their health as very good (M = 21.9, SD = 3.5). Of particular concern, the coldest 5% of dwellings with HRPs in very bad health reported having thermostat settings of 17.6˚C or below. Furthermore, households with disabled occupants indicated having a higher mean thermostat setting (M = 21.5, SD = 3.3) than dwellings with no disabled residents (M = 20.2, SD = 3.2).

Regarding the motivation, behaviour and perception characteristics, the analysis showed that households which indicated that they find it very difficult to afford their energy bills, also reported choosing much higher thermostat settings (M = 22.2, SD = 4.2) than those that stated their energy bills were very easy to afford (M = 19.1, SD = 2.0). The upper 95% CI indicated that 5% of the respondents which found it very difficult to afford their energy bills reported using thermostat settings of 25.7˚C or higher.

The results also suggest that households which are not worried about their energy bills or do not think about how they could save energy tend to choose higher thermostat temperatures for their homes. In addition, respondents reporting that they frequently or always close their curtains or blinds when the heating is on in the evening also stated lower average winter thermostat settings.

Respondents that strongly agreed that they did not understand how their home used energy had much warmer average heating setpoint temperatures (M = 23.0, SD = 4.9) than households which neither agreed nor disagreed (M = 20.2, SD = 2.9). The warmest 5% of households reporting that they did not understand how their home used energy selected thermostat settings of 26.8˚C or higher. Households that strongly disagreed that they could not save any more energy at home had higher average thermostat settings (M = 22.4, SD = 3.5) than those which neither agreed nor disagreed (M = 20.4, SD = 2.5).

Participants that stated there was always someone at home during the heating season reported winter thermostat settings that were on average 1.2˚C warmer (M = 21.6, SD = 3.0) than those dwellings which were partially occupied (M = 20.4, SD = 3.5). In addition, the results for weekday and weekend occupancy periods showed that the greatest difference in thermostat settings occurred during weekday daytimes, with occupied homes reporting a setpoint temperature of 21.2˚C and unoccupied homes 20.5˚C. During other occupation periods, the thermostat setting was on average 0.1-0.3˚C higher during occupied times.

Table 4 Reported mean winter heating setpoint temperature and dwelling, household and motivation, behaviour and perception characteristics

	Reported winter heating setpoint temperature (^{o}C)		
Dwelling characteristics	n	Mean (95% CI)	SD
All dwellings	111	20.9 (20.2, 21.5)	3.3
Dwelling type			
End terrace house	27	20.5 (19.3, 21.6)	2.9
Mid terrace house	28	20.9 (19.7, 22.1)	3.1
Semi-detached house	8	22.9 (20.0, 25.9)	3.6
Semi-detached bungalow	9	20.1 (18.4, 21.8)	2.2
Flat	33	20.9 (19.4, 22.3)	4.1
Maisonette	6	20.8 (18.4, 23.3)	2.3
Period dwelling was built			
Pre 1990	15	21.4 (19.3, 23.6)	3.9
1900-1949	4	20.3 (18.7, 21.8)	1.0
1967-1975	30	21.2 (20.0, 22.4)	3.3
1976-1982	21	20.3 (18.5, 22.2)	4.0
1983-1990	12	21.5 (19.4, 23.5)	3.2
1991-1995	15	20.4 (19.4, 21.5)	2.0
1996-2002	7	21.8 (19.7, 23.9)	2.3
Post 2007	7	19.3 (15.0, 23.5)	4.6
Number of floors			
1	57	21.0 (20.1, 21.9)	3.4
2	52	20.8 (19.9, 21.7)	3.2
Number of habitable rooms			

2	24	20.9 (19.2, 22.5)	4.0
3	41	20.7 (19.7, 21.7)	3.3
4	38	20.6 (19.8, 21.5)	2.7
5-6	8	22.9 (19.2, 26.7)	4.5
Wall construction type			
Cavity	52	21.6 (20.8, 22.5)	3.1
Solid wall	49	20.3 (19.3, 21.3)	3.4
Timber frame	10	19.8 (16.9, 22.6)	3.9
Wall insulation			
Thermal upgrades installed (cavity or solid wall insulation)	49	21.7 (20.8, 22.6)	3.2
As built	62	20.2 (19.4, 21.1)	3.3
Roof construction type			
Pitched with loft access	83	20.8 (20.1, 21.5)	3.1
Flat	9	20.0 (16.5, 23.5)	4.6
Other dwelling above	5	20.6 (15.7, 25.5)	3.9
Roof insulation thickness			
50-100mm	12	21.5 (19.3, 23.7)	3.5
150mm	34	20.5 (19.4, 21.7)	3.3
200mm	12	21.9 (20.2, 23.6)	2.7
250mm+	17	20.5 (19.4, 21.6)	2.0
Window type			
PVC double glazed	69	20.9 (20.2, 21.6)	3.0
Timber painted single glazed	3	20.0 (7.8, 32.4)	5.0
Window installation year			
1982-1989	5	22.6 (15.7, 29.5)	5.6
1990-1994	9	20.8 (19.9, 21.7)	1.2
1995-1999	20	20.8 (19.5, 22.0)	2.6
2000-2004	29	20.2 (19.1, 21.3)	3.0
2005-2009	3	22.0 (15.4, 28.6)	2.6
Post 2010	5	22.2 (16.8, 27.6)	4.4
Front door type			
Composite	19	20.1 (18.6, 21.5)	3.0
Metal	3	20.0 (7.6, 32.4)	5.0
PVC	47	21.1 (20.2, 21.9)	2.9
Timber	10	21.9 (19.1, 24.6)	3.8
Front door installation year			
1970-1989	13	22.6 (19.8, 25.3)	4.5
1990-1994	8	20.9 (19.6, 22.2)	1.5
1995-1999	20	20.2 (18.9, 21.5)	2.8
2000-2004	11	21.8 (20.3, 23.3)	2.3
2005-2009	12	19.8 (17.7, 21.8)	3.2
Post 2010	15	20.6 (19.2, 22.0)	2.6
Back door type			
Composite	3	20.0 (20.0, 20.0)	0.0
Patio	4	21.0 (19.7, 22.3)	0.8
PVC	18	20.3 (19.0, 21.6)	2.6
Timber	17	20.2 (19.0, 21.5)	2.4
Back door installation year			
1970-1989	6	21.3 (18.8, 23.7)	2.4
1990-1994	13	20.3 (19.2, 21.4)	1.8
1995-1999	9	20.4 (18.7, 22.0)	2.1
2000-2004	12	19.8 (17.8, 21.7)	3.0
Post 2005	4	21.3 (17.3, 25.2)	2.5
Heating system type			
Combi	39	20.8 (20.1, 21.6)	2.4
Condensing combi	68	20.8 (19.9, 21.7)	3.6
SAP			
0-25	10	20.2 (18.9, 21.4)	1.7
26-50	2	21.0 (21.0, 21.0)	0.0
51-75	92	20.9 (20.2, 21.6)	3.3
Household characteristics			
Age of HRP			
18-29	5	21.0 (19.5, 22.5)	1.2
30-39	14	21.0 (18.6, 23.4)	4.1
40-49	13	19.8 (17.8, 21.7)	3.2
50-59	17	22.2 (20.3, 24.1)	3.7
60-69	22	20.3 (18.9, 21.8)	3.2
70-79	14	20.6 (18.4, 22.9)	3.9
80+	14	21.4 (19.6, 23.1)	3.0
Household size			
1	52	21.0 (20.3, 21.8)	2.8
2	36	21.3 (20.0, 22.5)	3.7
3	14	19.3 (16.9, 21.7)	4.2
4	5	20.9 (18.3, 23.5)	2.1
5+	4	20.5 (13.1, 27.9)	4.7

Household composition			
One person	52	21.1 (20.3, 21.8)	2.8
Couple, no dependent children	40	20.9 (19.7, 22.1)	3.7
Couple with dependent child(ren)	12	21.6 (19.2, 24.1)	3.8
Lone parent with dependent child(ren)	7	17.9 (14.8, 20.9)	3.3
Highest qualification of HRP			
Secondary level	24	20.6 (19.6, 21.7)	2.5
Tertiary level	15	20.6 (19.5, 21.7)	2.0
Degree level or above	11	21.5 (19.2, 23.7)	3.3
Another kind of qualification	11	22.0 (20.2, 23.7)	2.6
No qualifications	29	21.0 (19.4, 22.6)	4.2
Household in receipt of welfare benefits			
Yes	55	21.2 (20.3, 22.1)	3.3
No	46	20.3 (19.4, 21.3)	3.2
Health of HRP			
Very good	11	21.9 (19.5, 24.2)	3.5
Good	34	20.0 (18.9, 21.1)	3.1
Fair	32	21.2 (20.2, 22.2)	2.7
Bad	14	22.0 (20.0, 24.1)	3.6
Very bad	14	20.1 (17.6, 22.7)	4.3
Household has disabled members			
Yes	58	21.5 (20.6, 22.4)	3.3
No	53	20.2 (19.3, 21.1)	3.2
Motivation, behaviour and perception characteristics			
Affordability of energy bills			
Very easy	7	19.1 (17.3, 21.0)	2.0
Fairly easy	26	20.8 (19.5, 22.2)	3.4
Neither easy nor difficult	45	21.3 (20.3, 22.2)	3.1
Fairly difficult	23	20.5 (19.0, 22.1)	3.6
Very difficult	8	22.2 (18.7, 25.7)	4.2
I am worried about my energy bills			
Strongly agree	17	21.3 (18.7, 23.8)	4.9
Tend to agree	42	21.1 (20.4, 21.8)	2.3
Neither agree nor disagree	25	19.8 (18.5, 21.2)	3.3
Tend to disagree	8	22.0 (18.9, 25.1)	3.7
Strongly disagree	10	22.5 (20.2, 24.8)	3.2
I don't understand how my home uses energy			
Strongly agree	9	23.0 (19.2, 26.8)	4.9
Tend to agree	34	20.8 (19.7, 21.8)	2.9
Neither agree nor disagree	24	20.2 (19.0, 21.4)	2.9
Tend to disagree	16	21.4 (19.9, 22.9)	2.8
Strongly disagree	12	21.8 (20.5, 23.1)	2.0
I often think about how I could save energy			
Strongly agree	29	21.8 (20.2, 23.3)	4.0
Tend to agree	45	20.3 (19.5, 21.2)	2.7
Neither agree nor disagree	17	21.3 (19.7, 22.8)	3.1
Tend to disagree	3	18.0 (11.4, 24.6)	2.6
Strongly disagree	9	22.1 (20.4, 23.8)	2.2
I have control over how much energy is used in my home			
Strongly agree	25	21.6 (20.5, 22.8)	2.8
Tend to agree	39	19.9 (19.0, 20.7)	2.5
Neither agree nor disagree	22	21.2 19.7, 22.7)	3.5
Tend to disagree	8	21.4 (17.2, 25.6)	5.0
Strongly disagree	8	21.9 (18.8, 25.0)	3.7
I am not able to save any more energy			
Strongly agree	14	21.2 (18.4, 24.0)	4.9
Tend to agree	36	20.8 (19.7, 22.0)	3.3
Neither agree nor disagree	31	20.4 (19.5, 21.3)	2.5
Tend to disagree	8	20.6 (19.8, 21.3)	0.9
Strongly disagree	8	22.4 (19.5, 25.3)	3.5
I make sure that the curtains/blinds are closed when the heating is on in the evening			
Always	60	20.9 (20.0, 21.8)	3.5
Often	26	20.9 (19.6, 22.3)	3.3
Sometimes	12	20.4 (18.5, 22.3)	3.0
Very occasionally	3	22.0 (15.4, 28.6)	2.6
Never	7	21.5 (17.8, 25.2)	4.0
I wear very warm clothes in winter so I can keep the heating low or off			
Always	51	21.6 (20.5, 22.6)	3.7
Often	30	19.6 (18.8, 20.4)	2.2
Sometimes	17	21.6 (20.2, 22.9)	2.6
Very occasionally	4	17.3 (10.0, 24.5)	4.6
Never	8	20.9 (18.2, 23.7)	3.3
I turn off the heating in rooms that are not normally used			

Always	42	20.7 (19.4, 21.9)	4.0
Often	17	20.3 (18.9, 21.6)	2.6
Sometimes	16	20.9 (19.4, 22.4)	2.7
Very occasionally	11	23.1 (20.8, 25.5)	3.5
Never	18	20.7 (19.4, 22.0)	2.7
I close the doors between rooms			
Always	42	20.9 (19.8, 22.0)	3.5
Often	20	21.4 (20.2, 22.6)	2.6
Sometimes	20	20.7 (19.1, 22.2)	3.4
Very occasionally	12	21.3 (19.2, 23.4)	3.3
Never	15	19.7 (17.6, 21.8)	3.8
Dwelling occupancy pattern during heating season			
Always occupied	47	21.6 (20.7, 22.4)	3.0
Partially occupied	63	20.4 (19.5, 21.3)	3.5
Occupied during weekday daytimes	60	21.2 (20.4, 21.9)	3.0
Unoccupied during weekday daytimes	51	20.5 (19.5, 21.6)	3.7
Occupied during weekday evenings	69	20.9 (20.2, 21.7)	3.1
Unoccupied during weekday evenings	41	20.8 (19.6, 21.9)	3.8
Occupied during weekend daytimes	60	21.0 (20.2, 21.8)	3.0
Unoccupied during weekend daytimes	50	20.7 (19.6, 21.8)	3.7
Occupied during weekend evenings	70	21.0 (20.3, 21.7)	3.0
Unoccupied during weekend evenings	40	20.7 (19.4, 22.0)	4.0
Highly variable	31	20.6 (19.3, 21.9)	3.7

Note: Sometimes not all households answered a question and so the total is less than 111.

5.2. Number of heating periods on weekdays and weekend days

Double heating periods (i.e. two sets of ‘on-off’ periods) were the most common heating pattern reported for both weekdays (n = 68, 45.9%) and weekend days (n = 59, 40.7%). Single heating periods (i.e. one set of ‘on-off’ periods) were used in 24.3% (n = 36) and 20.7% (n = 30) of dwellings during weekdays and weekend days respectively. The lower proportion of single and double heating periods recorded during weekend days was offset by an increase in triple and 24 h heating periods; triple periods (i.e. three sets of ‘on-off periods) were reported for 9.5% (n = 14) of homes during weekdays but 11% (n = 16) during weekend days. Similarly, reported 24 h heating periods (i.e. heating always on) in dwellings increased from 20.3% (n = 30) during the week to 27.6% (n = 40) at weekends.

5.3. Mean duration of heating periods on weekdays and weekend days

Table 5 shows the variations in reported duration of weekday and weekend day heating periods in relation to dwelling, household, and motivation, behaviour and perception characteristics. The analyses were undertaken for all households except those reporting heating their homes for 24 h. Households with 24 h heating periods greatly skewed the mean number of heating hours per day. Sub analyses were also undertaken for homes using single and double heating periods. The sample sizes for households using triple periods were too small for subgroup analysis.

Overall, the average weekday and weekend day heating durations for all homes were 9.5 h and 11.2 h respectively. Dwellings with single heating periods were calculated as having the longest mean weekday heating durations (6.2 h), which compares with 5.6 h for homes using double and 5.7 h for those using triple heating patterns. During the weekend, reported heating durations were more similar; the average durations of single and triple heating periods were both 6.4 h and double heating periods 6.1 h. Average daily heating duration was longer during weekend days than weekdays.

The analysis of households reporting using single and double heating patterns identified differences in the duration of heating in relation to the number of habitable rooms and construction. Participants living in dwellings with five or six habitable rooms and using a single heating pattern reported much longer weekend heating periods (M = 14.0, SD = 1.4) compared to dwellings with a lower number of habitable rooms, although this result should be treated with caution due to the small sample size. Dwellings of timber frame construction using a double heating pattern on weekdays also had longer heating durations (M = 7.4, SD = 3.0) than cavity wall (M = 6.0, SD = 2.8) and solid wall properties (M = 5.0, SD = 2.0). Furthermore, households residing in dwellings that had undergone thermal upgrades to the walls and used single heating patterns had greater weekday (M = 8.4, SD = 5.1) and weekend day heating periods (M = 8.6, SD = 5.2) than those in their as built condition (weekday: M = 4.9, SD = 4.6 and weekend: M = 5.3, SD = 4.8). Overall, this relationship was also evident, when homes using all heating patterns (excl. 24 h) were analysed as a single group, but only for weekdays (thermal upgrades: M = 6.5, SD = 3.9 and as built: M = 5.4, SD = 3.3).

An interesting relationship between windows and front doors installed between 2005 and 2009 and durations of double heating patterns also emerged. Households living in dwellings with front doors installed during that period of time reported longer heating durations on weekdays (M = 9.0, SD = 3.7), than those with doors installed after 2010 (M = 5.2, SD = 2.1). Dwellings with windows installed between 2005 and 2009 also had greater weekend heating periods (M = 10.5, SD = 0.7) than those with windows installed from 2000 to 2004 (M = 5.4, SD = 2.5).

In relation to the household characteristics, differences in heating durations were identified between households of different compositions, welfare benefit status and health. Single parent families using double heating patterns during the week had much shorter heating durations (M = 4.3, SD = 1.8) than couples with no dependent children (M = 6.7, SD = 3.2). Although this finding should be treated with caution due to the small number of single parent families.

Also, households in receipt of welfare benefits with double heating periods had shorter heating durations during the weekend (M = 5.4, SD = 2.5) than those not receiving welfare benefits (M = 6.8, SD = 1.8).

Furthermore, the health of the occupants appears to have an important relationship with the length of heating period. Households with double heating patterns and a HRP reporting being in bad health in the last 12 months had shorter heating periods during the week (M = 4.0, SD = 2.7) compared to homes with a HRP reporting, fair (M = 5.9, SD = 2.6) or good health (M = 6.7, SD = 2.5). This relationship was also evident for homes using a double heating pattern at the weekend (M = 3.3, SD = 1.4) compared to homes with a HRP reporting, fair (M = 6.5, SD = 1.8) or good health (M = 7.1, SD = 2.0). Moreover, households with disabled members reported longer heating durations during the week and weekend. In general, this relationship was apparent regardless of heating pattern used.

The analyses of the possible effects of motivation and perception characteristics on heating durations showed that households which reported either finding it very difficult to afford their energy bills, were worried about their energy bills or did not understand how their home uses energy generally had longer heating periods. Interestingly, households which strongly agreed that they were not able to save any more energy, in general, had greater average heating durations than those which believed they could save more energy.

The occupancy patterns of the dwellings were also found to have a range of effects on reported durations of weekday and weekend heating periods. In general, it was evident that dwellings which were occupied more often had longer winter heating periods during both weekdays and weekends, as well as during daytimes and evenings.

Table 5 Mean duration of heating periods on weekdays and weekend days and dwelling, household and motivation, behaviour and perception characteristics

	Duration of heating period on weekday (h) for each heating pattern						Duration of heating period on weekend day (h) for each heating pattern					
	All (excl. 24 h)		Single		Double		All (excl. 24 h)		Single		Double	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Dwelling characteristics												
All dwellings	118	5.8 (3.5)	36	6.2 (5.1)	68	5.6 (2.5)	114	7.8 (6.0)	30	6.4 (5.1)	59	6.1 (2.2)
Dwelling type												
End terrace house	25	6.2 (3.9)	6	8.3 (6.0)	14	5.5 (2.6)	25	9.8 (7.1)	5	7.6 (6.1)	10	7.1 (2.1)
Mid terrace house	34	5.2 (2.2)	8	4.3 (1.8)	22	5.5 (2.1)	33	6.3 (4.2)	6	5.7 (4.3)	22	5.9 (2.3)
Semi-detached house	9	6.2 (4.5)	3	6.7 (6.4)	5	6.7 (4.0)	9	9.3 (8.4)	1	2.0	6	5.7 (1.4)
Semi-detached bungalow	7	8.9 (4.7)	5	9.3 (5.5)	2	7.8 (2.5)	6	7.8 (3.9)	4	7.9 (4.8)	2	7.8 (2.5)
Flat	31	5.8 (4.0)	10	6.2 (6.2)	19	5.3 (2.6)	30	8.2 (6.7)	10	7.1 (6.3)	15	5.8 (2.4)
Maisonette	12	4.6 (2.1)	4	3.3 (1.5)	6	5.4 (2.3)	11	5.2 (2.2)	4	4.0 (2.4)	4	6.0 (2.5)
Period dwelling was built												
Pre 1990	17	5.1 (3.0)	6	5.8 (4.4)	10	5.1 (1.7)	17	10.6 (8.4)	4	8.3 (6.1)	7	6.9 (2.0)
1900-1949	5	4.3 (1.6)	1	3.0	3	5.0 (1.7)	5	5.2 (1.3)	1	3.0	2	6.0 (0.0)
1967-1975	24	6.7 (4.4)	12	7.6 (5.5)	9	5.2 (2.8)	22	7.7 (5.5)	7	8.1 (6.0)	11	5.6 (2.7)
1976-1982	21	6.6 (4.0)	5	7.8 (7.1)	14	6.4 (2.7)	20	8.5 (6.4)	6	7.7 (6.4)	11	6.5 (1.7)
1983-1990	11	4.1 (1.7)	4	3.6 (2.3)	6	4.1 (1.0)	10	5.5 (3.1)	4	6.1 (5.0)	4	4.5 (1.3)
1991-1995	22	5.8 (3.7)	5	6.2 (5.9)	15	6.1 (2.9)	22	6.5 (4.7)	5	3.6 (2.3)	15	6.5 (2.3)
1996-2002	12	5.9 (2.2)	1	7.0	8	5.4 (2.4)	12	9.5 (7.1)	1	7.0	6	5.6 (2.0)
Post 2007	6	5.3 (3.8)	2	2.0 (0.0)	3	6.2 (4.3)	6	5.3 (3.8)	2	2.0 (0.0)	3	6.2 (4.3)
Number of floors												
1	66	5.7 (3.8)	25	6.1 (5.3)	36	5.4 (2.5)	62	7.5 (6.1)	23	6.3 (5.2)	29	5.9 (2.3)
2	51	6.0 (3.2)	11	6.5 (4.7)	31	5.8 (2.6)	51	5.9 (0.8)	7	6.9 (5.3)	29	6.3 (2.2)
Number of habitable rooms												
2	23	5.5 (3.6)	6	4.9 (5.7)	16	5.6 (2.7)	22	7.8 (6.4)	7	6.2 (5.9)	13	5.9 (2.5)
3	48	5.7 (3.6)	17	6.4 (5.1)	24	5.3 (2.5)	46	6.5 (4.4)	15	6.8 (5.0)	21	5.8 (2.7)
4	40	6.1 (3.4)	10	6.0 (5.0)	25	6.2 (2.5)	39	8.7 (7.0)	6	3.2 (1.7)	23	6.4 (1.6)
5-6	7	6.0 (4.2)	3	8.8 (5.6)	3	3.6 (1.0)	7	11.1 (6.7)	2	14.0 (1.4)	2	7.0 (0.0)
Wall construction type												
Cavity	53	6.5 (3.7)	16	8.0 (4.9)	31	6.0 (2.8)	50	8.4 (6.0)	12	8.0 (5.0)	28	6.1 (1.8)
Solid wall	54	5.1 (3.0)	15	4.7 (4.6)	32	5.0 (2.0)	53	7.4 (5.9)	14	6.2 (5.4)	26	5.8 (2.5)
Timber frame	10	6.2 (4.8)	4	5.5 (7.0)	5	7.4 (3.0)	10	4.9 (3.4)	4	2.3 (0.5)	5	7.4 (3.0)
Wall insulation												
Thermal upgrades installed (cavity or solid wall insulation)	43	6.5 (3.9)	14	8.4 (5.1)	23	6.0 (2.6)	40	8.1 (5.6)	10	8.6 (5.2)	23	6.2 (1.7)
As built	75	5.4 (3.3)	22	4.9 (4.6)	45	5.4 (2.5)	74	7.6 (6.2)	20	5.3 (4.8)	36	6.1 (2.5)
Roof construction type												
Pitched with loft access	89	5.7 (3.4)	27	6.0 (4.7)	49	5.6 (2.6)	87	7.7 (6.0)	20	5.8 (4.6)	45	6.1 (2.2)
Pitched no loft access	1	5.0	0	-	1	5.0	1	8.0	0	-	1	8.0
Flat	9	5.2 (1.1)	1	4.0	8	5.4 (1.0)	9	10.7 (8.0)	2	8.0 (5.7)	5	6.5 (2.2)
Other dwelling above	7	4.4 (2.4)	1	0.5	6	5.0 (1.8)	7	5.4 (3.2)	1	0.5	5	6.2 (2.9)
Roof insulation thickness												
50-100mm	12	5.0 (2.2)	5	4.2 (2.3)	7	5.6 (2.1)	12	7.7 (5.6)	3	3.7 (2.9)	7	7.3 (1.1)
150mm	41	5.7 (3.5)	11	5.9 (5.2)	24	5.4 (2.7)	41	7.3 (5.7)	10	5.8 (5.0)	22	5.9 (2.2)

200mm	9	5.0 (2.6)	0	-	6	6.1 (2.2)	9	5.4 (2.4)	0	-	7	6.1 (1.9)
250mm+	19	6.8 (3.9)	8	8.1 (5.5)	9	6.1 (1.6)	17	10.8 (7.9)	4	7.3 (5.0)	6	6.5 (1.8)
Window type												
PVC double glazed	73	5.9 (3.5)	21	6.8 (5.0)	42	5.6 (2.4)	71	7.9 (6.1)	15	6.2 (4.7)	39	6.1 (2.1)
Timber painted double glazed	2	9.3 (2.5)	1	7.5	1	11.0	2	12.0 (1.4)	1	13.0	1	11.0
Window installation year												
1982-1989	4	4.5 (0.5)	2	4.0 (0.0)	2	4.9 (0.1)	4	11.5 (8.3)	0	-	3	7.3 (0.6)
1990-1994	11	5.7 (4.4)	3	7.0 (7.8)	6	6.1 (2.9)	11	5.1 (2.5)	3	2.7 (0.6)	6	6.7 (2.0)
1995-1999	27	5.8 (3.0)	6	6.0 (4.6)	18	5.8 (2.5)	26	9.3 (7.6)	4	4.0 (2.9)	14	6.0 (1.5)
2000-2004	26	5.9 (3.8)	8	7.1 (5.2)	14	5.0 (2.5)	25	6.9 (5.0)	6	7.9 (5.1)	14	5.4 (2.5)
2005-2009	4	8.3 (2.1)	2	6.8 (1.1)	2	9.8 (1.8)	4	10.0 (2.9)	2	9.5 (4.9)	2	10.5 (0.7)
Post 2010	3	8.8 (5.3)	1	15.0	1	6.0	3	10.0 (4.6)	1	15.0	1	6.0
Front door type												
Composite	25	5.8 (3.3)	4	7.3 (6.3)	18	5.7 (2.6)	25	7.0 (5.5)	4	4.0 (2.4)	16	6.0 (1.9)
Metal	2	6.8 (6.0)	0	-	2	6.8 (6.0)	2	6.8 (6.0)	0	-	2	6.8 (6.0)
PVC	46	6.3 (3.8)	16	6.8 (5.0)	23	6.0 (2.9)	43	8.6 (6.5)	11	7.0 (5.1)	21	6.3 (2.2)
Timber	14	5.2 (3.3)	5	6.7 (4.9)	7	4.1 (1.7)	14	7.7 (6.0)	4	9.0 (5.8)	6	5.0 (2.1)
Front door installation year												
1970-1989	15	5.6 (4.1)	6	7.5 (5.8)	7	4.0 (1.6)	15	9.0 (7.2)	4	9.5 (6.4)	6	5.3 (2.3)
1990-1994	8	4.9 (3.1)	2	2.5 (0.7)	5	5.7 (3.6)	8	5.3 (3.4)	2	2.5 (0.7)	5	5.7 (3.6)
1995-1999	23	6.1 (2.9)	4	7.8 (4.3)	14	5.3 (2.0)	22	9.7 (7.2)	1	7.0	12	6.0 (1.8)
2000-2004	8	7.3 (5.3)	5	9.1 (5.6)	2	6.0 (2.8)	7	4.4 (1.7)	4	8.1 (4.7)	2	5.5 (2.1)
2005-2009	12	7.3 (3.8)	4	4.4 (2.8)	7	9.0 (3.7)	11	6.2 (1.9)	4	5.8 (5.2)	6	8.1 (2.6)
Post 2010	21	5.3 (3.2)	4	7.0 (6.4)	15	5.2 (2.1)	21	4.8 (1.0)	4	5.8 (5.3)	14	5.9 (1.9)
Back door type												
Composite	2	2.5 (0.7)	0	-	2	2.5 (0.7)	2	5.5 (0.7)	0	-	1	5.0
Patio	3	4.5 (3.0)	0	-	2	5.5 (3.5)	3	6.2 (3.2)	0	-	2	8.0 (0.0)
PVC	22	5.9 (3.4)	5	6.2 (5.9)	14	6.3 (2.5)	22	7.3 (5.8)	5	3.6 (2.3)	13	6.2 (1.7)
Timber	22	5.4 (3.4)	6	3.3 (1.2)	13	5.5 (3.5)	21	8.3 (7.3)	4	5.0 (5.4)	11	5.0 (2.5)
Back door installation year												
1970-1989	5	5.4 (5.1)	3	5.3 (3.2)	2	5.5 (0.7)	5	10.4 (8.1)	2	7.0 (5.7)	2	7.0 (1.4)
1990-1994	13	5.5 (2.7)	4	6.3 (6.7)	8	6.9 (3.8)	13	7.0 (6.3)	4	5.0 (5.4)	7	6.4 (3.2)
1995-1999	16	4.9 (2.4)	2	3.5 (3.5)	12	5.0 (2.0)	16	7.9 (6.6)	2	3.5 (3.5)	9	5.7 (1.9)
2000-2004	10	6.3 (4.6)	1	4.0	5	5.0 (1.6)	10	8.2 (6.1)	0	-	6	5.3 (1.3)
Post 2005	5	5.4 (2.3)	2	4.0 (2.8)	3	6.3 (6.7)	4	4.8 (1.9)	2	4.0 (2.8)	2	5.0
Heating system type												
Combi	49	6.0 (3.5)	17	5.9 (4.8)	29	5.8 (2.5)	48	7.4 (5.5)	17	5.9 (4.8)	24	6.2 (2.3)
Condensing combi	67	5.7 (3.6)	18	6.7 (5.5)	38	5.4 (2.6)	64	8.1 (6.4)	13	7.1 (5.6)	33	6.0 (2.3)
SAP												
0-25	13	5.3 (1.8)	3	4.3 (0.6)	8	6.0 (1.8)	13	10.7 (8.0)	2	8.5 (6.4)	7	6.8 (1.1)
26-50	2	4.3 (3.2)	0	-	2	4.3 (3.2)	2	4.8 (2.4)	0	-	1	6.5
51-75	97	6.0 (3.7)	30	6.8 (5.4)	56	5.5 (2.5)	93	7.6 (5.8)	26	6.6 (5.2)	48	5.9 (2.3)
75-100	4	5.3 (4.3)	2	2.0 (0.0)	2	8.5 (3.5)	4	5.3 (4.3)	2	2.0 (0.0)	2	8.5 (3.5)

Household characteristics												
Age of HRP												
18-29	6	6.7 (2.8)	1	2.0	5	7.6 (1.9)	6	6.3 (2.5)	1	2.0	5	7.1 (1.5)
30-39	11	6.5 (4.4)	2	9.0 (9.9)	6	6.1 (3.5)	11	8.3 (6.4)	2	9.0 (9.9)	6	5.8 (1.7)
40-49	9	6.6 (4.4)	4	7.0 (5.7)	4	4.8 (1.9)	8	10.9 (8.6)	4	5.0 (2.6)	2	5.5 (0.7)
50-59	25	6.5 (3.9)	7	9.4 (5.3)	14	5.2 (2.4)	25	6.9 (4.8)	7	9.6 (7.5)	13	5.9 (2.7)
60-69	30	5.7 (3.3)	10	5.0 (4.1)	19	6.3 (2.8)	29	7.4 (5.7)	10	7.5 (7.4)	15	6.6 (2.1)
70-79	11	4.9 (1.4)	2	4.5 (0.7)	7	4.6 (1.5)	11	8.5 (6.0)	2	8.5 (6.4)	6	6.0 (2.8)
80+	11	3.7 (1.8)	4	2.8 (1.5)	5	3.9 (1.8)	10	6.7 (6.6)	3	3.3 (3.2)	5	5.7 (2.6)
Household size												
1	58	5.4 (3.0)	19	5.7 (4.4)	34	5.2 (2.1)	56	8.1 (6.4)	18	8.2 (7.3)	25	6.3 (2.4)
2	39	7.0 (4.1)	12	7.3 (6.0)	20	6.7 (3.3)	38	8.0 (5.2)	12	8.8 (7.1)	20	6.5 (2.3)
3	13	5.3 (3.7)	3	8.0 (6.6)	9	4.9 (2.0)	12	6.4 (6.0)	2	4.5 (3.5)	8	5.4 (2.0)
4	6	3.4 (1.8)	2	1.8 (0.4)	3	4.8 (1.3)	6	3.8 (1.8)	2	1.8 (0.4)	4	4.9 (1.0)
5+	2	4.9 (0.1)	0	-	2	4.9 (0.1)	2	14.4 (13.6)	0	-	1	4.8
Household composition												
One person	58	5.4 (3.0)	19	5.7 (4.4)	34	5.2 (2.1)	56	8.1 (6.4)	18	8.2 (7.3)	25	6.3 (2.4)
Couple, no dependent children	43	6.6 (4.1)	14	6.9 (5.7)	22	6.7 (3.2)	42	7.8 (5.8)	14	8.2 (6.8)	22	6.3 (2.4)
Couple with dependent child(ren)	13	5.1 (3.3)	2	8.5 (9.2)	10	4.7 (1.3)	12	6.4 (5.7)	1	2.0	10	5.0 (0.9)
Lone parent with dependent child(ren)	4	5.6 (4.5)	1	2.0	2	4.3 (1.8)	4	7.1 (4.2)	1	2.0	1	8.5
Highest qualification of HRP												
Secondary level	37	5.8 (3.1)	8	4.6 (4.4)	24	5.9 (2.4)	37	8.8 (6.8)	8	7.4 (8.1)	20	6.4 (2.1)
Tertiary level	18	5.5 (3.3)	6	6.6 (4.9)	9	5.0 (2.3)	17	7.1 (5.2)	5	9.8 (8.9)	8	6.0 (2.2)
Degree level or above	8	4.2 (1.7)	2	4.0 (0.0)	5	4.9 (1.3)	7	10.3 (9.6)	2	5.5 (2.1)	2	6.5 (0.7)
Another kind of qualification	10	6.9 (4.0)	4	9.5 (9.5)	4	4.9 (2.0)	10	8.4 (6.2)	4	12.5 (8.5)	6	5.6 (1.8)
No qualifications	26	5.9 (4.0)	8	5.8 (5.7)	16	5.9 (3.2)	25	7.1 (5.2)	8	6.8 (5.9)	13	6.1 (2.8)
Household in receipt of welfare benefits												
Yes	57	6.2 (4.5)	18	7.6 (6.2)	30	5.6 (3.3)	55	8.1 (6.8)	17	8.9 (8.0)	27	5.4 (2.5)
No	56	5.4 (2.3)	16	4.9 (3.3)	35	5.6 (1.8)	54	7.7 (5.3)	15	6.9 (6.1)	28	6.8 (1.8)
Health of HRP												
Very good	16	4.4 (2.2)	3	5.0 (3.6)	10	4.4 (1.9)	16	5.4 (2.6)	3	6.7 (4.5)	9	5.2 (2.5)
Good	29	6.4 (2.4)	6	5.6 (2.0)	22	6.7 (2.5)**	29	9.0 (5.7)	6	8.2 (4.3)	19	7.1 (2.0)
Fair	36	5.8 (3.2)	11	5.9 (4.5)	22	5.9 (2.6)**	32	7.3 (5.0)	9	7.5 (7.0)	19	6.5 (1.8)
Bad	19	5.7 (4.8)	6	6.5 (7.1)	6	4.0 (2.7)**	19	6.3 (6.0)	6	4.3 (5.4)	6	3.3 (1.4)
Very bad	14	7.0 (5.2)	7	9.4 (6.7)	7	4.6 (1.2)	14	12.5 (8.7)	7	13.9 (9.1)	4	6.1 (1.7)
Household has disabled members												
Yes	57	6.3 (4.3)	20	7.3 (6.0)	30	5.8 (3.1)	55	8.3 (6.7)	19	9.8 (8.3)	28	5.9 (2.5)
No	61	5.4 (2.5)	16	5.0 (3.4)	38	5.4 (1.9)	59	7.3 (5.2)	15	5.3 (3.5)	30	6.3 (1.9)
Motivation, behaviour and perception characteristics												
Affordability of energy bills												
Very easy	7	3.9 (2.8)	2	1.0 (0.7)	5	5.1 (2.5)	7	4.1 (2.9)	2	1.0 (0.7)	5	5.4 (2.3)
Fairly easy	23	6.3 (3.6)	9	6.4 (5.1)	12	6.4 (2.4)	21	7.6 (4.9)	6	7.0 (5.1)	12	6.8 (2.3)
Neither easy nor difficult	53	5.9 (3.0)	11	6.2 (4.7)	34	5.5 (2.2)	53	8.3 (5.9)	11	6.8 (5.0)	28	6.5 (2.1)
Fairly difficult	25	5.4 (3.7)	10	6.2 (4.6)	12	4.9 (3.3)	23	7.6 (6.2)	7	7.4 (5.3)	10	4.8 (1.9)
Very difficult	10	6.6 (5.6)	4	8.5 (8.1)	5	6.3 (2.9)	10	8.5 (9.2)	4	5.3 (6.6)	3	5.0 (2.6)
I am worried about my energy bills												

Strongly agree	18	6.1 (4.0)	7	6.6 (5.7)	11	5.8 (2.7)	17	10.6 (8.5)	5	7.6 (6.6)	8	5.8 (2.6)
Tend to agree	42	6.4 (3.8)	14	7.0 (5.1)	23	6.0 (3.2)	41	8.5 (6.0)	12	6.8 (4.9)	18	6.9 (2.0)
Neither agree nor disagree	32	5.2 (2.5)	5	3.9 (2.4)	20	5.5 (1.8)	31	7.2 (4.6)	5	8.4 (5.9)	19	6.3 (2.4)
Tend to disagree	9	5.1 (3.6)	3	7.0 (6.1)	5	4.2 (1.8)	9	6.3 (6.8)	2	3.5 (0.7)	5	4.2 (1.8)
Strongly disagree	11	4.7 (3.6)	5	4.8 (5.6)	5	4.3 (1.2)	11	5.0 (3.1)	5	4.4 (4.7)	4	5.0 (0.8)
I don't understand how my home uses energy												
Strongly agree	11	6.2 (3.5)	6	6.6 (4.5)	3	4.3 (1.1)	11	9.8 (6.1)	5	9.8 (5.5)	3	6.3 (1.2)
Tend to agree	35	5.8 (2.9)	8	6.6 (4.9)	24	5.5 (2.3)	34	8.3 (6.4)	7	7.1 (4.6)	19	6.0 (2.0)
Neither agree nor disagree	29	5.0 (3.0)	7	3.1 (1.7)	18	5.5 (2.8)	29	7.2 (5.5)	5	3.3 (2.9)	19	6.3 (2.8)
Tend to disagree	13	6.8 (4.8)	4	10.8 (6.7)	8	5.2 (2.5)	13	6.3 (4.0)	4	8.0 (6.7)	7	5.5 (2.5)
Strongly disagree	14	5.1 (3.2)	3	2.5 (1.8)	8	5.8 (3.4)	12	7.2 (6.2)	4	4.9 (4.9)	3	5.2 (0.8)
I often think about how I could save energy												
Strongly agree	33	5.9 (3.6)	13	6.0 (4.4)	16	5.7 (3.4)	32	8.1 (6.2)	9	6.8 (5.4)	16	6.0 (2.2)
Tend to agree	49	6.0 (3.4)	13	6.6 (5.4)	29	5.7 (2.0)	47	8.8 (6.7)	13	7.1 (5.2)	20	6.4 (1.7)
Neither agree nor disagree	15	5.1 (3.8)	4	4.8 (6.8)	9	5.8 (2.4)	14	5.1 (3.3)	3	1.3 (0.6)	9	6.7 (3.0)
Tend to disagree	6	3.6 (1.2)	1	5.0	4	3.2 (1.2)	6	5.5 (4.1)	1	13.0	4	3.8 (2.3)
Strongly disagree	10	6.5 (4.6)	5	7.5 (6.2)	5	5.4 (2.6)	10	7.7 (6.5)	4	5.4 (4.9)	4	6.4 (2.1)
I have control over how much energy is used in my home												
Strongly agree	25	5.9 (3.7)	7	8.1 (5.8)	17	4.9 (2.0)	24	8.3 (6.8)	5	7.5 (5.6)	13	5.4 (1.9)
Tend to agree	49	5.9 (3.3)	15	6.3 (5.1)	27	6.1 (2.2)	47	7.9 (5.8)	11	6.6 (5.3)	25	6.8 (1.6)
Neither agree nor disagree	19	5.5 (3.6)	3	3.0 (1.7)	12	6.0 (3.6)	18	7.6 (5.5)	4	7.3 (6.1)	9	5.9 (3.3)
Tend to disagree	13	6.9 (4.6)	5	8.3 (7.0)	6	5.2 (2.0)	13	9.4 (7.7)	5	6.8 (6.6)	4	5.6 (1.6)
Strongly disagree	8	4.0 (2.7)	6	3.8 (2.1)	2	4.9 (5.1)	8	4.6 (3.2)	5	3.7 (2.4)	3	6.1 (4.4)
I am not able to save any more energy												
Strongly agree	17	7.4 (4.6)	6	9.2 (6.5)	9	6.5 (3.5)	16	9.6 (6.8)	4	9.3 (7.3)	8	6.3 (1.9)
Tend to agree	43	5.3 (2.3)	12	4.6 (2.2)	24	5.5 (2.2)	43	7.6 (5.4)	9	6.7 (4.6)	22	6.5 (2.2)
Neither agree nor disagree	30	6.8 (4.3)	10	7.9 (6.1)	15	6.6 (2.8)	28	8.4 (6.4)	7	5.9 (5.3)	13	6.8 (2.4)
Tend to disagree	11	4.2 (2.2)	1	1.0	10	4.6 (2.0)	10	9.1 (8.4)	2	6.5 (7.8)	6	5.0 (2.1)
Strongly disagree	5	4.5 (1.9)	3	4.5 (2.6)	2	4.5 (0.7)	5	4.5 (1.9)	3	4.5 (2.6)	2	4.5 (0.7)
I make sure that the curtains/blinds are closed when the heating is on in the evening												
Always	70	5.8 (3.5)	24	6.3 (4.9)	38	5.7 (2.4)	70	7.7 (5.7)	22	6.9 (5.2)	31	6.6 (2.1)
Often	25	6.4 (4.2)	8	7.9 (6.0)	14	5.8 (3.2)	21	6.7 (5.1)	5	6.6 (5.5)	13	5.2 (2.2)
Sometimes	12	5.9 (3.0)	2	2.3 (2.5)	9	6.0 (2.0)	12	9.1 (7.6)	2	2.3 (2.5)	7	6.4 (2.2)
Very occasionally	2	3.5 (0.7)	0	-	2	3.5 (0.7)	2	6.0 (2.8)	0	-	2	6.0 (2.8)
Never	5	3.9 (1.3)	0	-	3	3.8 (1.6)	5	12.3 (10.8)	0	-	3	4.5 (2.5)
I wear very warm clothes in winter so I can keep the heating low or off												
Always	54	5.9 (4.2)	24	7.0 (5.5)	25	5.3 (2.5)	48	6.9 (5.6)	17	7.3 (5.8)	24	6.2 (2.5)
Often	34	5.2 (2.6)	7	4.0 (2.9)	19	4.9 (1.9)	13	10.3 (7.3)	8	5.3 (4.3)	15	5.0 (1.9)
Sometimes	15	6.7 (3.2)	1	4.0	14	6.9 (3.3)	15	8.4 (7.1)	1	4.0	9	6.9 (1.4)
Very occasionally	4	4.0 (1.3)	1	2.0	3	4.6 (0.2)	6	6.6 (3.2)	1	2.0	3	5.3 (1.4)
Never	10	6.3 (3.4)	3	7.3 (6.1)	6	6.2 (2.0)	21	7.3 (4.6)	3	6.7 (5.0)	6	7.3 (2.4)
I turn off the heating in rooms that are not normally used												
Always	49	5.8 (4.1)	14	6.1 (5.9)	28	5.9 (3.3)	48	6.9 (5.6)	13	5.6 (5.4)	24	6.2 (2.6)
Often	13	6.0 (3.6)	4	7.3 (6.3)	9	5.5 (1.8)	13	10.3 (7.3)	5	9.8 (5.9)	5	6.2 (2.2)
Sometimes	17	6.4 (4.0)	5	7.2 (6.7)	9	5.0 (1.6)	15	8.4 (7.1)	3	5.0 (6.1)	6	5.3 (1.8)
Very occasionally	6	6.3 (2.7)	2	7.5 (2.1)	4	5.6 (3.0)	6	6.6 (3.2)	2	8.5 (3.5)	4	5.6 (3.0)
Never	22	5.4 (2.6)	9	5.4 (3.7)	12	5.6 (1.4)	21	7.3 (4.6)	6	5.0 (4.2)	13	7.2 (1.3)

I close the doors between rooms												
Always	46	6.0 (4.0)	15	6.3 (5.7)	26	5.6 (2.7)	45	6.8 (5.1)	14	5.9 (5.2)	23	6.0 (2.5)
Often	22	4.9 (2.6)	7	4.3 (2.4)	12	5.6 (2.9)	21	8.3 (7.1)	5	6.4 (5.2)	10	5.3 (1.7)
Sometimes	18	5.5 (2.3)	1	1.0	15	5.6 (2.2)	18	9.0 (7.4)	2	6.5 (7.8)	10	5.8 (2.3)
Very occasionally	12	5.0 (2.6)	3	4.3 (2.9)	7	5.1 (2.4)	12	7.5 (5.7)	2	3.5 (3.5)	7	6.4 (1.8)
Never	16	6.6 (4.2)	8	7.9 (5.5)	7	5.5 (2.0)	14	8.0 (5.7)	5	6.8 (5.3)	7	7.1 (2.2)
Dwelling occupancy pattern during heating season												
Always occupied	43	7.6 (4.3)	14	9.8 (5.6)	22	6.3 (3.2)	42	9.1 (6.2)	11	10.0 (5.6)	20	5.9 (2.4)
Partially occupied	75	4.8 (2.5)	22	3.9 (3.0)	46	5.3 (2.1)	72	7.0 (5.8)	19	4.3 (3.4)	38	6.2 (2.2)
Occupied during weekday daytimes	58	7.0 (4.1)	16	9.2 (5.6)	31	6.3 (3.0)	57	8.3 (5.6)	14	9.0 (5.4)	27	6.3 (2.3)
Unoccupied during weekday daytimes	60	4.6 (2.4)	20	3.9 (3.1)	37	5.0 (1.9)	57	7.3 (6.4)	16	4.1 (3.6)	31	6.0 (2.2)
Occupied during weekday evenings	82	6.3 (3.7)	22	7.5 (5.5)	49	5.8 (2.6)	80	8.3 (5.9)	20	7.9 (5.5)	39	6.2 (2.2)
Unoccupied during weekday evenings	36	4.6 (2.9)	14	4.2 (3.6)	19	5.1 (2.4)	34	6.6 (6.0)	10	3.4 (2.4)	19	5.8 (2.2)
Occupied during weekend daytimes	63	6.8 (3.8)	17	8.9 (5.5)	38	5.8 (2.7)	62	8.7 (6.1)	14	8.9 (5.4)	32	6.1 (2.2)
Unoccupied during weekend daytimes	55	4.6 (2.7)	19	3.8 (3.2)	30	5.3 (2.3)	52	6.7 (5.8)	16	4.2 (3.8)	26	6.1 (2.2)
Occupied during weekend evenings	75	6.3 (3.7)	22	7.6 (5.4	43	5.8 (2.6)	74	8.2 (5.8)	19	7.8 (5.4)	37	6.2 (2.1)
Unoccupied during weekend evenings	43	4.8 (2.9)	14	4.1 (3.7)	25	5.3 (2.4)	40	7.1 (6.4)	11	3.9 (3.5)	21	5.9 (2.4)
Highly variable	33	5.2 (2.8)	10	5.6 (3.9)	19	5.4 (2.0)	31	6.9 (4.4)	9	7.1 (4.3)	17	6.4 (2.3)

6. Discussion

6.1. Space heating preferences in UK social housing

The findings reported in this paper suggest that heating setpoint temperatures and durations can vary considerably among UK social houses. This finding is consistent with the work of others for owner-occupied and privately rented homes [20-24]. Some systematic relationships between heating setpoint temperature, duration, and dwelling, household, and motivation, behaviour and perception characteristics are found. Some salient observations and discussions stemming from the analysis undertaken follow.

Overall, the mean reported winter thermostat setting of the sample was 20.9˚C. This value is similar to those estimated from temperature measurements using sensors in a number of recent UK studies: Kane et al. [20] in their city-scale study of owner-occupied and privately rented homes reported an identical mean setpoint temperature of 20.9˚C; nationally, Huebner et al. [21-22] quoted an average demand temperature of 20.6˚C and Shipworth et al. [24] an average thermostat setting of 21.1˚C (average participant self-reported thermostat setting however was lower at 19.0˚C). The consistent result obtained in the current study suggests that on average heating setpoint temperatures in social housing are similar to those used in the wider housing stock. The mean setpoint value obtained is also similar to the 21˚C recommended by the World Health Organisation (WHO) as a comfortable indoor temperature, and to prevent potential health effects [105].

The average weekday and weekend heating durations were 9.5 h and 11.2 h respectively. Shipworth et al. [24] using internal temperature measurements previously reported heating durations of 8.2 h for weekdays and 8.4 h for weekends. In the same study, participant self-reported heating periods were longer at 9.4 h for weekdays and 9.8 h for weekend days. Kane et al. [20] estimated an average daily heating duration of 12.6 h, but did not report the difference between weekdays and weekends. It was however acknowledged by the authors that this duration is likely overestimated, because of an issue in their method with estimating heating start times. The mean weekday heating duration obtained in the current study is quite similar to those reported by others. However the average weekend heating duration appears to be longer than those reported in earlier studies. This may indicate that on average households living in social housing heat their homes for longer than other tenure types during the weekend.

The results obtained for dwelling characteristics provide evidence of rebound effects in social housing which has undergone refurbishment. Households with thermal upgrades installed (cavity or solid wall insulation) had higher average setpoint temperatures and, in general, longer heating durations during weekdays and weekends. In addition the most energy efficient homes (i.e. higher SAP ratings) and those with newer windows had higher mean setpoint temperatures. This finding suggests that actual energy savings from refurbishment of social housing is likely to be lower than predicted as occupants may change their heating preferences to improve their thermal comfort rather than benefit from the potential energy savings. The current results support previous findings that the rebound or take-back effect is evident in the social housing sector [10,15].

Single parent families were found to have cooler thermostat settings than other household compositions. This result may reflect the lower average household incomes of single parent families. Although the effect of household income on heating setpoint temperature was not available, previous studies have identified significant effects of income on heating preferences [28,39,46,52,54]. The average heating setpoint temperature reported in lone parent homes (17.9˚C) is much lower than the 21˚C recommended by the WHO. The coldest 5% of dwellings occupied by single parent families reported heating setpoint temperatures of 14.8˚C or below. In these households the health effects are likely to be severe. The heating preferences of single parent families and the consequent health impacts could be an area for further investigation and potentially of concern for government policy makers as well as local authority and social housing associations.

The reported health of the dwelling occupants appeared to have a relationship with space heating preferences. Dwellings with disabled members had higher mean thermostat settings (21.5˚C) and generally longer heating periods during weekdays and weekends. For the social housing sector, in which a greater proportion of dwellings are occupied by disabled people, this result has important implications, as theoretical energy savings from social interventions (i.e. behaviour change) to encourage reductions in thermostat settings or heating durations may well be limited by the occupants' health. Thermal upgrades to homes occupied by disabled people are therefore essential to deliver suitable indoor environments at lower energy demands and financial costs.

Furthermore, dwellings occupied by HRPs which considered their general health in the last 12 months as very bad were observed as having lower setpoint temperatures (20.1˚C) than those in very good health (21.9˚C). In addition, they also had shorter heating durations during weekdays and weekends when a double heating pattern was used. Of particular concern, the coldest 5% of dwellings with HRPs in very bad health also reported having thermostat settings of 17.6˚C or below. The direction of this relationship may well be two-fold; firstly, the HRP's bad health limits their potential to work and as a result have low household incomes, meaning thermal comfort and health is sacrificed in order to reduce energy costs. Secondly, the low internal temperatures and shorter heating durations themselves, contribute to the bad health of the HRP.

Households which reported that it was very difficult to afford their energy bills were also found to have higher thermostat settings (22.2˚C) than those stating it was very easy (19.1˚C). In addition, the upper 95% CI indicated that 5% of the respondents which found it very difficult to afford their energy bills reported using thermostat settings of 25.7˚C or higher. This result suggests that a possible avenue for reducing energy bills would be to encourage this group to reduce their winter heating temperatures at home to the 21˚C recommended by the WHO.

In addition, households which strongly agreed that they did not understand how their home used energy also had warmer thermostat settings (23.0˚C) than households that neither agreed nor disagreed with the statement (20.2˚C). The warmest 5% of households reporting that they did not understand how their home used energy selected thermostat settings of 26.8˚C or higher. This finding suggests that by improving understanding and engagement in energy efficiency at home, households may respond by lowering their heating setpoints, resulting in reductions in heating energy use.

Households which believed they could save more energy chose higher thermostat settings (22.4˚C) than those that neither agreed nor disagreed (20.4˚C). This is an interesting finding as this group of households appear to be conscious of their potential to reduce energy use, but this does not translate into energy saving actions. Additional work to understand the barriers to action, particularly around their operation of heating controls, would be valuable.

Finally, the occupancy pattern of dwellings during the heating season appears to have a strong relationship with heating setpoint temperatures and durations. Dwellings which were always occupied had higher thermostat settings. In addition, dwellings which were occupied more often had longer heating periods during both weekdays and weekends, as well as during daytimes and evenings. This is a positive finding as it highlights that during periods when homes are unoccupied, households are likely to reduce their thermostat setting or heating duration or turn off their heating.

6.2. Applications for the research

The research reported in this study should be of interest to a number of key groups, including, government policy makers, local authority and social housing associations, energy supply companies, energy distribution network operators, as well as energy modellers.

The dwellings and households identified as having the highest thermostat settings and longest heating durations could be targeted for energy efficiency measures (i.e. thermal upgrades) and social interventions (i.e. behaviour change). These dwellings and households are likely to benefit most from such interventions and therefore could be prioritised for government schemes such as the Energy Company Obligation (ECO), which obligates large energy suppliers to deliver energy efficiency measures in domestic buildings. Prioritisation of certain dwellings will become increasingly important given the 20% budget reduction planned in the scheme from March 2017. Furthermore, local authority and housing associations, as well as local and national government could use these findings to target energy campaigns at those households in their housing stocks where space heating demand is likely to be highest.

The results provided by this paper highlight the dwelling, household, and motivation, behaviour and perception characteristics affecting heating preferences in domestic buildings, these could be used to inform how space heating demand in the housing sector might change as the building stock and socio-economic profile of the nation evolves in future. These characteristics could also be mapped on to other UK national datasets to identify where hot-spots of high heat demand may exist or develop and where future heat networks will require additional capacity.

Furthermore, the findings obtained in this work have pertinent implications for the energy modelling of UK social housing. The results could be used to assist the energy modelling community when predicting the space heating demands of social housing and the potential energy savings from refurbishment measures. Recent studies [17] have stated that there is little guidance regarding the values that should be assigned for energy modelling of domestic buildings and that standardised heating patterns in Simplified Building Energy Models (SBEM) misrepresent the variability of heating preferences in real homes [20-24]. The current work further corroborates these sentiments. Whilst the average heating setpoint temperature (20.9˚C) matched well with values recommended in a number of previous energy modelling studies [34,73,82,87-88,94,96] and standards [18-19,92-93], the mean heating durations for weekdays and weekends were generally shorter than those previously used by others. Moreover, large variability in heating setpoint temperatures and periods were observed according to dwelling, household, and motivation, behaviour and perception characteristics. This finding suggests that when predicting space heating energy demands and potential energy savings from refurbishment of individual homes, standardised assumptions about heating preferences, such as those recommended in BREDEM [18], BS EN ISO 13790 [19], CIBSE [89-91] and DOE [92-93], may not be suitable and are likely to produce unreliable predictions.

6.3. Limitations and future research

The results obtained in this study are based on relatively small sample sizes (111 dwellings for heating setpoint temperature and 148 for weekday and 145 for weekend day heating periods) from a single UK city and therefore extrapolating the results to the wider population of UK social housing or owner-occupied or privately rented homes is not appropriate. A larger national-scale study of heating setpoint temperatures and periods in UK social housing would therefore be a valuable extension to the current work and could also be used to validate the findings of the current study. Previous UK studies at the national [103] and city-scales [104] have primarily excluded the social housing stock in their analyses so these data offer a valuable contribution to the field.

The reliability of the self-report data provided by the survey participants is an overarching concern for all energy use surveys. Previous studies have found inconsistencies between self-reported and actual thermostat settings used in homes [24,106]. The accuracy of the data may be affected both by the respondents' inability to remember their heating setpoint temperature and duration (recollection bias), as well as their intentional under-reporting to appear more energy efficient, in order to please the researchers or to conform with others (social desirability bias). In addition, heating setpoint temperatures and periods can also change over time. A number of recent studies are developing techniques to overcome this issue, such as using high resolution indoor air temperature measurements to infer heating setpoints and durations [20-24] and requesting households to upload photographs of their thermostats using crowdsourcing services [107]. As noted in the BS EN ISO

13790 standard, using indoor temperature data however to infer heating setpoints, should be done with caution as *"internal temperature is not the same as the setpoint due to effects such as overheating, intermittency, inertia, imperfect control"*. In addition, Kane et al. [20] state that the method of using measured internal temperature data tends to *"overestimate the start time and so the duration of heating period"*.

To date, research undertaking direct measurements of thermostat settings and durations in homes has been limited by the availability of commercial/off-the-shelf monitoring equipment. To the authors' knowledge, Andersen et al.'s [33] study in Denmark, which developed a custom monitoring device, is the only study to provide direct measurement of heating setpoints in homes. However, with the rapid development of 'smart' Internet-connected thermostats, which allow users to control their heating via a website or on their smart phone, data about heating preferences will become increasing available. The large scale penetration of these devices in the housing stock however could take many years and it is not known whether the current heating setpoint temperatures and durations chosen by households will remain the same when they change from a manual or programmable thermostat to an Internet-connected device. Furthermore, early adopters of Internet-connected thermostats are also unlikely to be representative of the wider UK housing stock and therefore early findings obtained from these homes will be difficult to extrapolate to other households. In addition, possible issues with data security, sharing and the commercial value of the data are potential barriers to manufacturers of such devices making the information publically available for reuse in research and to inform government policy.

7. Conclusions

This paper provides an analysis of the relationships between dwelling, household, and motivation, behaviour and perception characteristics and heating setpoint temperatures and heating periods in UK social housing. The data analysed in this study were derived from a socio-technical household survey undertaken in Plymouth, UK, during 2015, as part of the EnerGAware project. The data collected from the survey were merged with building audit records held by the households' social housing association, which contained a comprehensive overview of the key structural elements and services in each home, as well as the dataset for the RdSAP energy rating methodology.

Overall, the mean reported winter thermostat setting of the sample was 20.9˚C and the average weekday and weekend heating durations were 9.5 h and 11.2 h respectively. The results of this study suggest that whilst heating setpoint temperatures and durations can vary greatly among UK social houses, this variation is not random; there are clear, systematic variations according to dwelling, household, and motivation, behaviour and perception characteristics.

The mean setpoint value obtained in this study was similar to the 21˚C recommended by the World Health Organisation (WHO) as a comfortable indoor temperature, and to prevent potential health effects. However, some concerning findings regarding the heating preferences of single parent families and households with a HRP in reported very bad health in the last 12 months emerged. The heating preferences of these households probably warrant further investigation as part of a national-scale study:

- Lone parent families reported an average setpoint temperature of 17.9˚C, much lower than the 21˚C recommended by the WHO. In addition, the coldest 5% of dwellings occupied by single parent families reported heating setpoint temperatures of 14.8˚C or below.
- Dwellings occupied by HRPs rating their general health in the last 12 months as very bad, reported setpoint temperatures of 20.1˚C and the coldest 5% of dwellings used thermostat settings of 17.6˚C or below. In addition, these households had shorter heating durations during weekdays and weekends when a double heating pattern was used.

The results of the study also suggest that additional research about households' understanding of heating controls, as well as potential barriers to reducing heating setpoint temperatures at home would be beneficial to design effective behaviour change interventions and energy efficiency campaigns. The study suggests that households do not prioritise reductions in their thermostat setting as an energy efficiency action even when they find it difficult to afford their energy bills or believe that they could save more energy:

- Households which reported that it was very difficult to afford their energy bills also used higher thermostat settings (22.2˚C), with 5% of the respondents reporting using thermostat settings of 25.7˚C or higher.
- Households which believed they could save more energy chose higher thermostat settings (22.4˚C).
- Households which did not understand how their home used energy had warmer thermostat settings (23.0˚C), with 5% of the households selecting thermostat settings of 26.8˚C or higher.

The results of the study also provide evidence of the rebound effect in social housing which has undergone refurbishment. Dwellings with thermal upgrades installed (cavity or solid wall insulation) had higher average setpoint temperatures and, in general, longer heating durations during weekdays and weekends. In addition, the most energy efficient homes (i.e. higher SAP ratings) and those with newer windows had higher mean setpoint temperatures. This finding suggests that actual energy savings from refurbishment of social housing is likely to be lower than predicted as occupants may change their heating preferences to improve their thermal comfort rather than benefit from the potential energy savings.

The research reported in this study could enable social housing providers, the government and other commercial organisations to target energy efficiency measures (i.e. thermal upgrades) and social interventions (i.e. behaviour change) at those dwellings and households where their impact may be most beneficial.

In addition, the results presented could be used to better inform the assumptions of heating preferences used in energy models, which could result in more realistic predictions of the space heating demands of social housing and the potential energy savings from refurbishment measures.

Acknowledgements

The research reported in this paper was undertaken as part of the EnerGAware project: Energy Game for Awareness of energy efficiency in social housing communities. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 649673.

The authors would like to thank DCH for sharing data held on their asset management and building stock condition database and their residents for participation in this study.

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