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Energy Follow Up Survey: thermal comfort, damp and ventilation

Final report

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Any enquiries regarding this publication should be sent to us at:
enquiries@beis.gov.uk

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Executive Summary

This report presents the findings of the EFUS 2017 thermal comfort, ventilation and damp and mould analysis. The findings are based on interviews conducted during the autumn of 2017 (Interview 1) and the winter of 2017/18 (Interview 2), the data collected from temperature loggers installed in homes between October 2017 and April 2019 and data collected from a mobile phone text survey undertaken during a hot period in sna stepummer 2018. The main findings are presented below:

Summer thermal comfort

- The measured overheating assessment used temperatures monitored in the living room and main bedroom during summer 2018 (the hottest summer to that date). Adaptive temperature thresholds (that recognise that people adapt to warmer temperatures), were used to calculate if overheating had occurred. The adaptive criterion method was expanded to enable the vulnerability of occupants to be taken into consideration by using a lower adaptive temperature threshold for the 'vulnerable' group and based on this 15% of households were classed as overheated in the living room, and 19% in the bedroom.
- Self-reported perceptions of summer thermal comfort were obtained from interviews that followed the previous cooler summer (2017), where 11% of households reported feeling uncomfortably warm ‘often’ or ‘all the time’ in the living room, and 17% in the bedroom.
- The findings for measured overheating support the use of the ‘adaptive’ criterion to provide a more credible approach to overheating assessment and enable more targeted approaches to mitigating overheating among the types of dwellings and households most at risk.
- Both measured and self-reported overheating provided indicative evidence of a higher prevalence of overheating in the main bedroom compared with the living room. There were some strong similarities in the self-reported and measured patterns of overheating within certain dwelling and socio-economic characteristics; overheating in living rooms was more prevalent in flats and the smallest dwellings, as well as low income households and the social sector tenure compared with their counterparts. In main bedrooms, both the self-reported and measured results showed a greater prevalence of overheating in households with greater number of occupants and with children present.
- There was a stark difference between the patterns of measured and self-reported incidence of overheating in homes occupied by older people. The measured prevalence of overheating in the living rooms of homes with a pensioner present was significantly greater than in other households. However, the self-reported prevalence of overheating in the living room was significantly lower for households with a pensioner present.
- The results suggest that older people either prefer higher temperatures and/or are poor detectors of temperature and therefore tend to under-report overheating. Future

research should therefore note that overheating studies based on self-reporting especially when they include responses from older people who are most vulnerable to heat, may be unreliable in the assessment of risk to health from high temperatures

- To illustrate the conditions in some homes during a particularly hot spell, a short text message survey was conducted at the end of June 2018. During this week the hottest 20% of households had an average living room temperature greater than 26.5°C; and in the main bedroom above 26.9°C. Some 38% of the sample reported uncomfortably hot conditions in their living room and 71% said they had found it difficult to sleep on one or more nights. The nature of this survey precluded more detailed analysis.

Winter thermal comfort

- Dwelling age, energy efficiency rating and number of insulation measures had the largest impact on the mean internal temperatures in the living room and main bedroom; the oldest (pre-1919) dwellings were significantly colder (mean living room 17.7°C) than newer dwellings (post-1990 dwellings mean living room 19.1°C) and the most energy inefficient (EPC rated F or G) dwellings had significantly colder living room (17.2°C) and main bedroom (15.7°C) temperatures compared with A to C and D rated dwellings (living room 18.6°C to 19.3°C; bedroom 17.8°C to 18.9°C). Dwellings in rural locations and those with non-central heating systems also had significantly colder bedrooms compared with those in urban and centrally heated dwellings, respectively. Households with a pensioner present had higher mean living room temperatures (compared with younger households), as did households in the lower income groups.
- Some 12% of households reported feeling uncomfortably cold (2.9 million) 'often' or 'all the time' in their living room, and 9% (2.2 million) in the main bedroom. Measured living room and main bedroom temperatures were lower (by 1.2°C and 2.4°C respectively) in those households that reported feeling uncomfortably cold.
- Although older occupants are most at risk, physiologically, of excess cold, results showed the following groups were more likely to report feeling uncomfortably cold: households in rented tenures, youngest households, lone parents with dependent children, households on the lowest incomes, those living in the oldest dwellings and the fuel poor (23% compared with 11% in households not in fuel poverty). There was no apparent relationship between households being uncomfortably cold and their heating hours or supplementary heating use, but households that reported a higher thermostat set point were more likely to feel cold.
- The most common reason reported by households feeling cold in their living room was draughts (49% of households that gave a reason), whereas for those feeling cold in their main bedroom it was poor insulation (38% of households that gave a reason). Other rooms that were reported to feel cold were, primarily, other bedrooms, bathrooms and kitchens.
- The coldest week was a week at the end of January/early February 2019, where external temperatures dropped to 0.9°C. Average internal temperatures were, for that

week, just under 1°C colder, both in living rooms and main bedrooms, compared with the Winter 2018/19 averages. The coldest 20% of households experienced an average living room temperature below 16.1°C and a main bedroom temperature below 15.6°C.

Winter ventilation, damp and mould

Overall, 10% of households reported no use of ventilation in their bathrooms whilst showering/bathing. A high proportion (83%) of households reported drying clothes indoors in winter, while just under half (47%) reported never ventilating the room whilst doing do.

- Some 6.5 million (27%) households reported the presence of some damp and/or mould patches on the walls or ceilings in their home, most commonly in a bedroom or a bathroom. The following groups were more likely to report damp/mould: households in fuel poverty (42%), lone parents with dependent children (48%), low income households (41%), older pre-1919 dwellings (39%) and the least energy efficiency dwellings (40%). Of those reporting a problem with damp/mould, 36% (2.3 million households) reported they had a medical condition made worse by damp.
- There was no apparent influence of householders' behaviours in terms of airing the house, ventilating the bathroom or drying clothes indoors on the prevalence of damp problems, but main bedrooms were colder in homes with damp compared with those without damp.

1. Introduction

There is an ongoing requirement to keep our knowledge and understanding of domestic energy use up to date. This is essential to ensure that policies, and policy interventions, are directed in the most efficient and effective manner; that legislation and standards are based on principles and assumptions that reflect how people are actually using energy in their homes; and that models and statistics which provide the underpinning evidence base in this area are as accurate as possible. Of particular relevance at the moment are policies relating to fuel poverty, decarbonisation of heat, smart metering and minimising household bills.

The data presented here is from the 2017 Energy Follow-Up Survey (EFUS). This was a follow-up survey of a sample of respondents from the English Housing Survey (2014 to 2017) and provided more detailed information on use of heating, hot water and appliances. Similar Energy Follow-Up Surveys were carried out in 1998 and 2011.

Today the Department of Business, Energy and Industrial Strategy (BEIS) has several overarching aims which need to be addressed by this new EFUS. These are:

1. To determine current domestic energy consumption and heating patterns in England and to investigate how they change over time through time-series comparisons.

2. To understand how and why there are variations in energy consumption between similar dwellings, and similarities in energy consumption between different dwellings.

3. To understand how households in fuel poverty use energy and how their energy consumption patterns and behaviours compare with non-fuel poor households.

The key questions addressed in this report on 'thermal comfort, ventilation and damp and mould' are:

Summer overheating;

- The prevalence of overheating in the summer? How do household perceptions of overheating compare with measured overheating using statistical modelling?
- How does overheating compare between dwelling types and among households?

Winter thermal comfort;

- What temperatures are households heating different rooms to and what temperatures are being achieved in the coldest weather conditions?
- What is the impact of external temperature on the ability of heating systems to meet desired temperatures in fuel poor and non-fuel poor households?
- How is winter thermal comfort related to the energy efficiency of homes and different dwelling and household characteristics?

Ventilation;

- How do households alleviate the moisture in their home arising from bathing/showers and indoor clothes drying?

Damp and mould;

- How is the presence of any damp related to dwelling and household characteristics?
- Have damp problems caused by poor ventilation led to health problems?

2. Methodology

Full details of the data collection and analysis methods used are set out in a separate methodology report, however, an outline is given below of the analysis, and the interview surveys upon which this report is based.

2.1 Surveys

The first of the householder surveys was undertaken in the autumn of 2017 and is referred to as Interview 1. A pilot survey of 94 households was carried out between May and June 2017, followed by the main survey of 1,867 households. This survey was conducted via a face-to-face interview conducted in the householder's home between August and October 2017. In order to boost the sample, an online version of the same survey was completed by a further 671 households between October and December, giving a total sample of 2,632.

The Interview 1 survey covered a number of areas including;

- Summer thermal comfort
- Cooling behaviours
- Hot water use
- Appliance use
- Lighting
- Energy tariffs and method of payment
- Dwelling improvements
- Changes to the household

The second of the householder surveys, a follow-up survey to Interview 1, was conducted between January and March 2018 and is referred to as Interview 2. To minimise disruption to the householders the survey was conducted via a telephone interview and 1,060 households completed the telephone survey. As with Interview 1, in order to boost the sample an online version of the Interview 2 survey was completed by a further 280 households giving a total sample of 1,340. Therefore almost 51% of the Interview 1 households also completed the Interview 2 survey.

The Interview 2 survey examined;

- Use of main, secondary and alternative heating systems
- Winter thermal comfort
- Winter ventilation behaviours
- Damp and mould

- Winter appliance and hot water use
- Lighting
- Trade-offs made by households unable to afford to heat their homes
- Occupancy patterns

The third of the householder surveys, another follow-up survey to Interview 1, was conducted between February and March 2019 and is referred to as Interview 3. The survey was conducted via a telephone interview and online survey; 447 households completed the telephone survey and a further 739 households responded online, giving a total sample of 1,186. Some 80% of the Interview 3 surveys had an Interview 1 and Interview 2 survey (944 households), while the remaining 242 households had an Interview 1 survey only. The interview 3 survey collected information on:

- Use of main heating systems including the heating season
- Proportion of the house heated
- Occupancy patterns
- Smart technologies
- Method of payment and tariffs
- Changes to property and household

The results presented in this report are based on the householder responses to questions from all three interview surveys. The respective survey is referenced within the text.

In addition, a short text message survey was conducted at the end of June 2018 during a particularly hot spell. The purpose of the survey was to assess the effects of the high temperatures on householders' thermal comfort and behaviour. Householders were sent four questions via text message. Of the 1,308 people to whom the text message was sent, between 353 and 376 responses were obtained for each question (27-29% of those sampled). There is the prospect of response bias in the results reported from the text survey, in particular, that those experiencing overheating might be more likely to respond to questions about the subject.

2.2 Temperature data

Temperature loggers were installed in 750 households from August 2017 until October 2017 and internal temperatures were monitored up until April 2019. Temperatures were recorded in up to five rooms in any one household; the living room, hallway, main bedroom and second and third bedrooms (if present). Weather data was obtained from the Met Office (MIDAS dataset). The Met Office MIDAS station closest to each household was identified, and the hourly external temperatures recorded by each station were time-matched to the temperature data recorded by the loggers.

Data was processed to calculate monthly and seasonal averages, including average temperatures during the coldest week of the year. Average internal temperatures were calculated for each room with data, and an average of the relevant rooms used to provide the whole dwelling average. The majority of households had at least three loggers installed, with one logger in the living room, hallway and main bedroom. Some 3.6% of households had only one logger installed, 10% had two, 43% had three, 25% had four and 18% of households had five rooms monitored. Further details are provided in the EFUS 2017 Methodology report.

Additional processing of the internal temperature data was carried out for the purpose of assessing summer overheating. The measured half-hourly values from the living room and main bedroom for the period from May to September were plotted and inspected by eye. Rooms were removed from the sample if: there was no recorded data; there were curious temperature spikes suggesting solar radiation or other heat source effects; loggers were recording very similar temperatures, suggesting the sensors had been placed in the same location; there were changes in the temperature trace, suggesting, perhaps, that the sensors had been moved; there were other ‘strange’, thermally inexplicable, data anomalies.

Altogether the data cleaning process removed 134 living rooms and 159 bedrooms from the sample leaving a total of 616 living rooms and 591 bedrooms for the summer overheating analysis. Interestingly, of the 517 homes for which both living room and bedroom temperatures were available, 285 (55.1%) displayed evidence of space heating at some time during the five-month period.[1] Such heating was usually for brief periods in the evening in the living room or the bedroom. In the analysis undertaken, no distinction was made between heated and unheated homes[2].

2.3 Weighting

The weighting factors for all three interview surveys were derived using a RIM weighting method and logistic regression, based on population targets so that the households in the EFUS dataset represent the number of households in England in 2017 (23.95 million) and 2018 (24.17 million). An additional weighting factor was derived for the subset of households with valid temperature logger data. The text survey sample size was too small to allow the findings to be weighted to population proportions. The analysis presented from the text survey is therefore unweighted and based on the percentage of people that provided each answer. Further details on the weighting methodology are provided in the separate methodology report.

2.4 Analysis

Statistical analysis was used to measure the significance of the findings presented in this report. All statistical analysis was conducted on weighted data, and a design effect factor was

[1] Space heating was characterised by sharp temperature rises, which could not be explained by solar gains, and which reoccurred at a similar time each day when occupants would probably be present in the room.
[2] Analysis showed that the prevalence of overheating in the heated and unheated rooms was very similar, but slightly less in the heated rooms.

used to account for the complex survey design. Further details on the analysis are provided in the full methodology report.

The key dependent variables used in each chapter have been analysed by the defined set of EFUS social demographic and dwelling characteristic variables (listed below). As a rule, only statistically significant results at the 99% level (where $p < 0.01$) have been included in the text, although there are some instances when results that are significant at the 95% level ($p < 0.05$) are reported.

Household characteristics: tenure, household composition, household size, presence of pensioner, presence of child, age of the HRP (household reference person), employment status of household, household income, daytime occupancy, anyone in the household designated long-term sick or disabled, under-occupying status, fuel poverty status.

Dwelling characteristics: dwelling type, house or flat, dwelling age, floor area, region, rurality, presence of central heating, main fuel used, wall type, insulated walls, loft insulation thickness, double glazing extent, number of insulation measures, Energy Performance Certificate (EPC) rating band.

Further details on these characteristics are located in the Glossary.

The following tests were used:

- The Chi-Squared (X2) test was used when comparing two categorical variables to determine if they are independent. Alongside this the Z-test for proportions was used to determine where the differences occur, with a Bonferroni correction. Cramer's V was used to analyse the effect size.
- McNemar's test was used when comparing two categorical variables, for a repeated measure.
- Analysis of Variance (ANOVA) was used with continuous data (e.g. measured temperatures) to determine the impact of categorical variables, and the Tukey post-hoc test was used to determine where the differences occur. In addition, the effect size Eta-squared (η2) has been calculated. Where assumptions for homogenous variances are violated, the result of the Welch test has been reported, and post-hoc testing has been conducted by independent t-tests.
- Paired T-tests were used when comparing two continuous variables, for a repeated measure.

All frequencies and percentages reported in the text have been rounded, with percentages rounded to the nearest percent. Measured temperatures have been rounded to the nearest tenth of a degree (°C).

In this report, where householders responded 'don't know' to a question, and if the proportion of 'don't know' responses was less than 5% of the unweighted sample then these were set to missing and excluded from the analysis.

2.4.1 Multi-variate analysis (MVA)

In addition to the bivariate analysis used throughout the report, logistic regression models were used to determine whether any subset of dwelling, households and EFUS variables were good predictors/drivers of self-reported summer overheating, self-reported winter thermal discomfort and reported damp and/or mould growth[3].

[3] Further details on the MVA methods used are presented in the EFUS Methodology Report

3. Weather conditions and overview of measured internal temperatures

This chapter provides context for the analysis presented in chapters 4 to 7 of this report, particularly the findings for summer and winter thermal discomfort. It presents a summary of the external weather conditions during the EFUS surveys and temperature monitoring period and a summary of the mean internal temperatures measured from October 2017 to April 2019 in living rooms and main bedrooms. Temperatures and descriptions of weather in this section are for the UK and taken from the Met Office[4],[5] unless otherwise specified.

3.1 External temperatures during the temperature monitoring period, 2017-2019

Overall, 2017, 2018 and 2019 were relatively hot years in comparison with the 30-year average (1981-2010) used by the Met Office. Figure 3.1 shows the monthly average external temperatures for England during the EFUS 2017 temperature monitoring period as compared to the 30-year average.

2017 was the fifth warmest year on record for the UK in a series since 1910. Summer 2017 was slightly warmer than the 1981 to 2010 average, largely due to a hot spell in June; the hottest June temperatures for over 40 years. Interview 1 ran from August to October 2017 and included questions about summer thermal comfort (section 4.2).

Winter 2017/2018 saw the most significant spell of snow and low temperatures since 2010 records. Interview 2 was undertaken from February to March 2018 and included questions about winter thermal comfort (section 5.2). This period included the cold wave beginning 22 February 2018, dubbed the 'Beast from the East' by the media, which brought widespread unusually low temperatures and heavy snowfall to large areas. Table 3.1 (top panel) shows the mean, minimum and maximum monthly external temperatures and the temperature anomaly for the winter months, including the 'winter' time period (December to February).

Summer 2018 was the joint hottest summer season (June, July, August) in the Met Office UK national temperature series dating from 1884[6] (Table 3.2) and it was the warmest on record for England. Summer average temperatures were close to +2°C above the 1981 to 2010 average for a large swathe of southern and central England and Wales[7]. It was noted by commentators that "The peak in temperatures coincided with a sharp increase in the daily death count for England (Office for National Statistics, 2018), …[8]". These commentators also considered that "there is a likelihood greater than 50%, of summers exceeding the 2018 temperatures by the

[4] https://www.metoffice.gov.uk/research/climate/maps-and-data/summaries/index
[5] https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-and-regional-series
[6] Hollis et al., 2019. HadUK-Grid version 1 dataset.
[7] McCarthy et al, 2019.
[8] Ibid.

mid twenty-first century". EFUS internal temperature measurements from this period have been used in the assessment of overheating reported in section 4.1.

Winter 2018/2019 –November and December 2018 were around 2°C warmer than the 30-year average, with temperatures dropping in January 2019. The coldest week in this winter period began on Monday 28th January 2019 and finished on Sunday 3rd February 2019. The average temperature for this period across England was 0.7°C which, although not as cold as the period in February 2018, benefitted from overlapping with the EFUS detailed gas consumption monitoring period. Analysis relating to this coldest week is presented in section 5.3. February 2019 went on to be the second warmest February in a series from 1910 and included a new UK winter maximum temperature record of 21.2°C at Kew Gardens. EFUS internal temperatures were measured until April 2019 (Table 3.1, bottom panel).

Figure 3.1: Met Office England monthly average external temperatures

Source: Met Office England Mean Temperature Areal Series (accessed 02/01/2020)

Table 3.1: Met Office temperature summaries for Winter 2017/2018 and Winter 2018/2019

	Winter 2017/18						
		2017			2018		
	October	November	December	January	February	March	April
							°C
Monthly mean							
Temperature	12.1	6.6	4.6	5.1	2.6	4.6	9.5
Temp. anomaly	1.8	-0.3	0.3	1.0	-1.5	-1.6	1.4
Mean daily maximum							
Temperature	15.3	9.9	7.6	7.9	5.7	7.9	13.2
Mean daily minimum							
Temperature	9.0	3.2	1.7	2.3	-0.4	1.4	5.9

	Winter 2018/19						
		2018			2019		
	October	November	December	January	February	March	April
							°C
Monthly mean							
Temperature	10.5	7.9	6.5	3.8	6.5	7.7	8.8
Temp. anomaly	0.2	1.1	2.2	-0.3	2.3	1.5	0.6
Mean daily maximum							
Temperature	14.6	10.8	9.2	6.6	10.9	11.3	13.7
Mean daily minimum							
Temperature	6.5	5.0	3.8	1.0	2.1	4.1	3.8

Temperature anomalies are relative to the month or winter mean for the period from 1981 to 2010.

Sources:

Met Office UK climate, summaries https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-and-regional-series accessed 19.05.20

Mean temperature anomalies (1981-2010 anomaly period; England) https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-temperature-rainfall-and-sunshine-anomaly-graphs accessed 19.05.20

Table 3.2: England Met Office temperature summaries for Summer 2018

		Summer 2018				Summer
	May	June	July	August	Sept	**Overall**
						°C
Monthly mean						
Temperature	13.0	15.8	18.8	16.8	13.7	17.2
Temp. anomaly	1.7	1.7	2.5	0.6	-0.1	2.3
Ranking	1st	4th	2nd	16th	45th	1st
Mean daily maximum						
Temperature	18.3	21.1	24.8	21.3	18.1	22.4
Mean daily minimum						
Temperature	7.6	10.6	12.9	12.2	9.2	11.9

Temperature anomalies are relative to the month or summer mean for the period from 1981 to 2010.

Rankings are relative, i.e. June 2018 had the 4th hottest mean temperature of any June in a series since 1910. Precision quoted is that provided in the source.

Sources:

Met Office, UK climate, summaries. Available at: https://www.metoffice.gov.uk/climate/uk/summaries Accessed 13/11/18 and https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-and-regional-series 23/11/19.

Mean temperature anomalies for May and Sept (1981-2010 anomaly period; England) from https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-temperature-rainfall-and-sunshine-anomaly-graphs Accessed 23/11/19.

3.2 Overview of the measured mean internal temperatures

A short discussion on the internal temperatures in all monitored rooms is presented here, but following on from this, temperatures in the living room and main bedroom are the focus of the analysis of winter and thermal comfort[9].

The mean internal temperatures experienced by all households typically mirrored the external temperature patterns in the summer months and flattened out to the average household heating temperature in the winter months. The highest mean internal temperatures occurred in July 2018 (24.4°C in the living room; 24.8°C in the main bedroom) while the lowest mean occurred in February 2018 (18.5°C in the living room; 18.1°C in the main bedroom), coinciding with the so-called ‘Beast from the East’ period of cold weather. The range of temperatures was large throughout the year, though considerably greater during the winter; the average minimum and maximum temperatures in living rooms in winter 2017/18 was 11°C and 29°C, respectively whereas in summer 2018 the respective values were 18°C and 28°C.

In winter 2017/18, living rooms were typically the warmest room being, on average, 0.4°C warmer than hallways, 0.5°C warmer than main bedrooms (Figure 3.2) and 0.8°C warmer than third bedrooms. Temperatures in hallways showed no significant differences, on average, to any bedrooms but the third bedroom was, on average, 0.5°C cooler than main bedrooms.

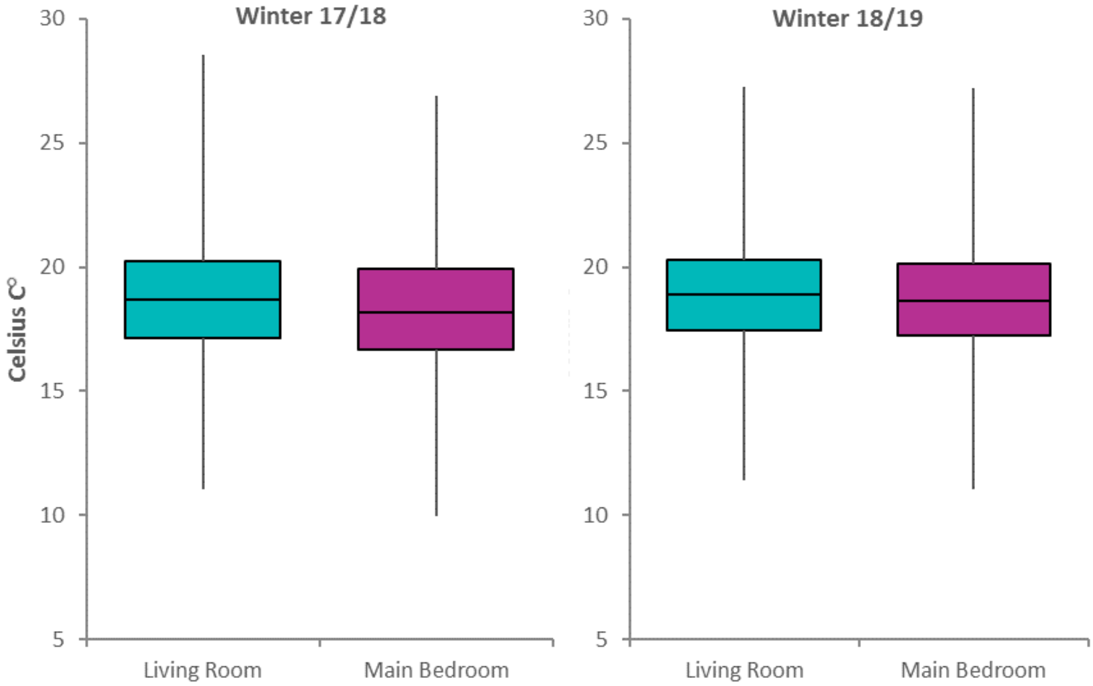
In comparison, in summer 2018, all bedrooms were on average hotter than living rooms (Figure 3.3) and hallways by between 0.4°C and 0.8°C. No significant difference in average temperatures was seen across bedrooms in the summer.

In winter 2017/18, the coldest 10% of households experienced an average living room temperature below 15.7°C; in the main bedroom the coldest 10% of households experienced temperatures below 15.0°C. This is a temperature that may be, at occupied times, below the

[9] Annex tables containing the underlying data for this section can be found in Tables_3_2.xls.

18°C threshold reported to cause, or make worse, ill health for occupants[10]. In the summer of 2018, the warmest 10% of households had an average internal temperature in their living room above 24.9°C, similarly 10% of households experienced temperatures in their main bedroom above 25.0°C. Further analysis on internal temperatures measured during the hottest week, and coldest week are provided in Sections 4.4 and 5.3 respectively.

Figure 3.2: Monthly mean internal temperatures in living room and main bedroom for Winter 2017/18 and Winter 2018/19[11]

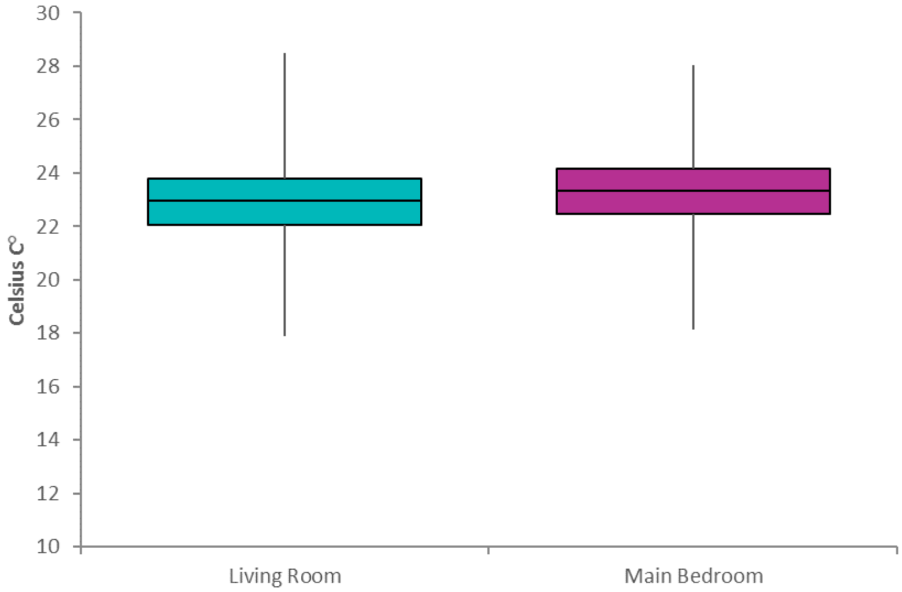


Base: All households in temperature monitoring sub-sample (n=691 living room, n=672 bedroom)

[10] See Public Health England report published October 2014 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/776497/Min_temp_threshold_for_homes_in_winter.pdf

[11] Boxplots show the minimum, lower quartile, median, upper quartile and maximum average temperatures.

Figure 3.3: Monthly mean internal temperatures in living room and main bedroom for Summer 2018



Base: All households in temperature monitoring sub-sample (n=691 living room, n=672 bedroom

4. Summer thermal comfort

This chapter examines summer thermal comfort using two approaches. Section 4.1 reports on the prevalence of overheating using measured indoor temperatures (made between May and September 2018). Section 4.2 uses data from Interview 1 and a text survey to explore householders' reported perceptions of overheating. A comparison between the results of the measured and self-reported assessments of overheating prevalence is then presented in Section 4.3, firstly by comparing the results of the two approaches across different households and then by looking at the extent to which measured and reported overheating coincides within households. Section 4.4 reports on the results of a text survey sent to householders following a particularly hot spell at the end of June 2018.

The two distinct ways of reporting overheating are important, as householders' responses should not be interpreted as a direct measure of whether rooms were actually overheated, as indicated by measured temperatures. People are not thermometers, and their perceptions of temperature are heavily influenced by their age, health and other personal and social factors. Neither is the self-reporting of overheating an indication of the risks to the health and well-being of an individual. Most notably, older people may have poor temperature perception and also poor thermo-regulatory capabilities[12]. They are also more likely to be on medication that impairs thermo-regulatory perception and regulation. Therefore, although high temperatures may not be perceived by older people, they could still be being exposed to health risks.

From the perspective of the EFUS, the measurements made during the summer of 2018 have the distinct advantage of being collected during record breaking summer heat, thus enabling the frequency of overheating in homes of different type and in different geographical areas to be studied along with the measures people take to combat heat. The disadvantage is that the results cannot readily be interpreted in the context of a typical UK summer; at least summers typical of the 2010s.

Householders' perceptions of overheating used data from the Interview 1, conducted between August and October 2017, and the summer text message survey, conducted in June 2018, which captured the perception of thermal comfort levels following a heat wave.

Analysis of the measured living room and main bedroom internal temperatures during the summer 2018 period, across the dwelling and socio-economic characteristics highlighted some differences which are summarised here to provide context for the assessments of overheating[13].

Dwellings in London had noticeably higher mean internal temperatures in the summer 2018 period in the living room (24.2°C) and bedroom (24.1°C) compared with other regions, with the coolest temperatures observed in the North East (21.8°C in the living room; 22.2°C in the bedroom). In addition, flats and dwellings with a smaller floor area were found to have warmer

[12] A person aged 65 years or over is most at risk of harm from excessive heat under the Housing Health and Safety Rating System (HHSRS)
[13] Annex tables containing the underlying data for this section can be found in Tables_4_0.xls.

mean internal living room temperatures. Cooler bedrooms were observed in pre-1919 dwellings, while both living rooms and bedrooms had cooler temperatures in dwellings with lower F to G energy efficiency ratings (21.9°C in the living room; 22.2°C in the bedroom) compared with dwellings in bands A to E. Perhaps, surprisingly, there were no differences in living room temperatures across the individual energy efficiency-related groups i.e. wall type and whether insulated, however main bedroom temperatures were 0.5°C warmer in dwellings with double glazing and results indicated warmer bedroom temperatures (at the 95% level) in dwellings with cavity walls compared with solid walls.

Local authority households had warmer living rooms than owner occupied or private rented households, and indicative results at the 95% level also indicated warmer bedrooms in local authority households. Households under-occupying their homes had cooler living rooms, with results also indicating (at the 95% level) cooler bedrooms in the highest income households. No significant differences were observed for households of different age groups (including pensioners), nor were there any clear trends for households of different sizes, nor by fuel poverty status.

4.1 Assessing overheating from measured summer temperatures

This section reports the prevalence of overheating based on temperature measurements made between May and September 2018 in the living room and main bedroom of a sample of 750 homes (616 homes with living room measurements; 591 homes with main bedroom measurements)[14].

There is no generally accepted and fully documented method for assessing, using field measurements, whether rooms in buildings are overheated. The various guidelines and standards, of which CIBSE Guide A (CIBSE, 2015), BSEN15251 (BSI, 2017), Technical Memorandum TM52 (CIBSE, 2013), and TM59 (CIBSE, 2017) are the most important, focus on assessment based on summertime temperatures predicted using dynamic thermal models. Although CIBSE Guide A, BSEN15251 and TM52 do include suggestions about assessment by measurement, the advice is far from comprehensive and in some areas inconsistent.

Two methods can be used to assess the prevalence of overheating based on measured temperatures:

The static criterion uses a fixed temperature threshold and states the number of hours exceedance of this threshold that is deemed to constitute overheating. Both the threshold and the exceedance values are fixed irrespective of the prevailing ambient temperatures

The adaptive criterion recognises that people adapt to warmer temperatures, both psychologically and physiologically, for example by wearing lighter clothing, using shading devices. This adaptation depends on previous daily temperatures that people have

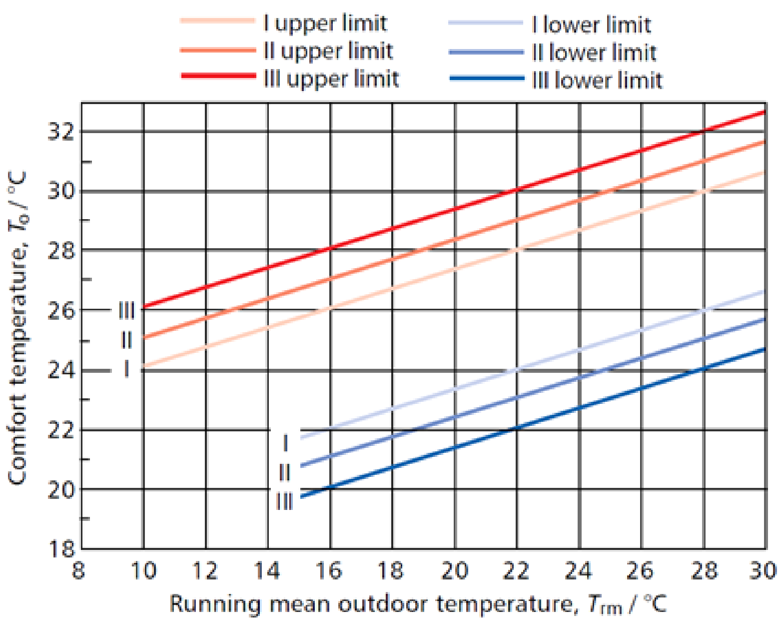
[14] Annex tables containing the underlying data for this section can be found in Tables_4_1.xls

experienced. The adaptive temperature threshold (Tmax), above which spaces are considered to be too warm, increases with the running mean of the mean daily outdoor temperature (Trm). The indoor operative temperature (TO) most closely relates to people's temperature perception.

The standard approach to determining overheating in the bedrooms of UK homes is to count the number of occupied hours over a fixed threshold of 26°C. This 'static' approach is based on a small study conducted back in 1975[15] and is increasingly contested by academics working in the field. There has been no work to develop alternative criteria for sleep, for example using adaptive thermal comfort considerations.

The adaptive approach is increasingly seen as a more credible method of assessing overheating and has been widely used for assessing overheating in living spaces based on measurement. Different thresholds have been established through field measurement above which people start to feel 'thermally uncomfortable'. These thresholds, shown in Figure 4.1, depend on the vulnerability (Category) of a room's occupants, being lower for those more susceptible to heat (Cat. I, 'sensitive and fragile persons'[16]) and higher for others (Cat. II, normal persons).

Figure 4.1: Adaptive thermal comfort thresholds, for three categories of people (Cat.I, II, and III); [17]



[15] Humphreys, 1979. The influence of season and ambient temperature on human clothing behaviour, in Fanger PO and Valbjorn O (eds.), Indoor Climate (Copenhagen: Danish Building Research)
[16] BSI (2007) BS EN 15251: 2007: Indoor environmental parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics (London: British Standards Institution)
[17] CIBSE (2013a) The limits of thermal comfort: avoiding overheating in European buildings CIBSE TM52 (London: Chartered Institution of Building Services Engineers)

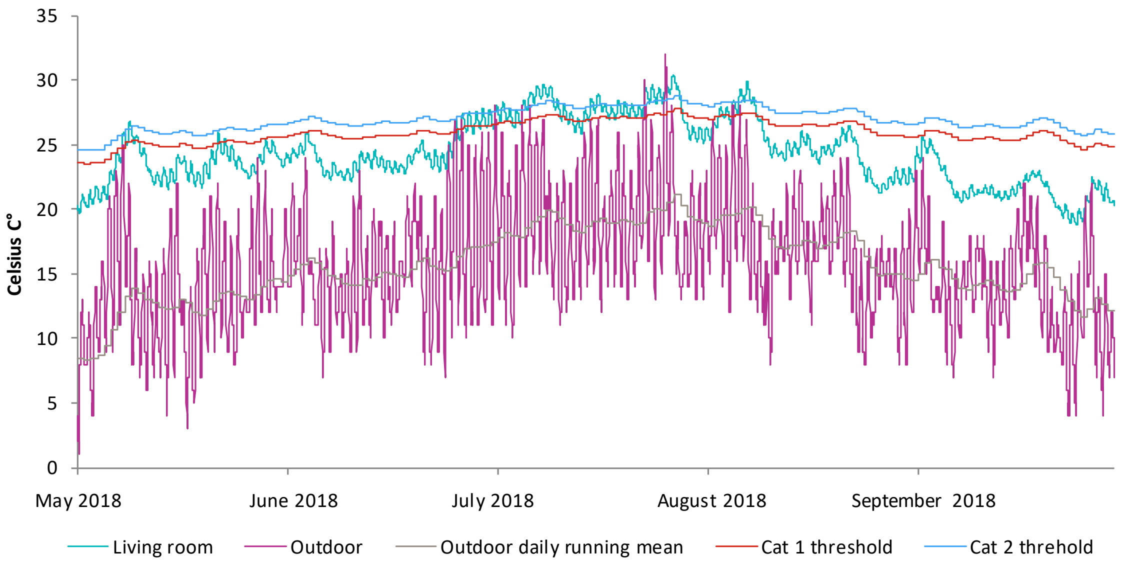
The difference between the room's measured operative temperature at any given time (To), and the relevant threshold (Tmax) for that day, ΔT, is calculated. Criteria, defining the frequency and degree of exceedance of these thresholds, determine what constitutes overheating. Three adaptive thermal comfort criteria are given in CIBSE Technical Memorandum TM52. In the adaptive thermal comfort analysis undertaken here, criterion 1 in TM52 is the focus[18] which states that:

- "The number of hours (He) during which ΔT is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 per cent of occupied hours[19]

That is, overheating was deemed to have occurred in the room if there were more than 3% of occupied hours during May to September in which the temperature was 1°C or more over the adaptive thermal comfort threshold. For both living rooms and bedrooms the adaptive overheating threshold was set firstly on the basis that all households were Cat. II (assuming non-vulnerable occupants) and secondly, with an additional element accounting for vulnerable households also used, where the following households were classified as Cat. I. for which the overheating threshold is 1°C lower: households with persons aged 75 or more, children under 5 years old, households with anyone long-term sick or registered disabled. Figure 4.2 shows an example of the adaptive threshold temperatures, and the running means of measured temperatures in a living room

[18] TM59 states that *'the thermal comfort category assumed based on CIBSE TM52 (2013);* [this] *should be Cat. II by default, but Cat. I for vulnerable residents; Cat. III for existing buildings should not be used for the purposes of this methodology'*.
[19] Interestingly, TM52 states that *'ΔT is rounded to the nearest whole degree (i.e. for ΔT between 0.5 and 1.5, the value used is 1 K; for ΔT between 1.5 to 2.5 the value used is 2 K, and so on)';* though no reason for doing this is given. Because of this rounding, any ΔT more than 0.5K above the thresholds, rather than 1K (as the criterion implies) fails the criterion. This convention was adopted in this work.

Figure 4.2: Example of measured temperatures between May and September in a 'hot' living room showing also the outdoor temperature the daily running mean of the outdoor temperature (Trm), and the adaptive thermal comfort Cat.I and Cat.II thresholds



The allocation of vulnerable (Cat. I) and non-vulnerable (Cat. II) households, referred to in this work as Selected Category (Sel.Cat.), was used as the focus of analysis throughout this report i.e. the appropriate thermal sensitivity was assigned to each household. Assigning the actual resident vulnerability provides the best assessment of the measured overheating risk and enables credible comparisons with the prevalence of self-reported overheating. Some 53% of households were classed as Cat.I within both the living room sample and the bedroom sample. The occupied hours for the living rooms was presumed to be 07:30 to 22:00 inclusive and for the bedrooms from 22:00 to 07:00 inclusive (see Appendix A for further details).

To provide a comparison, bedrooms were also assessed using the static criterion taken directly from TM59:

- "to guarantee comfort during the sleeping hours the operative temperature in the bedroom from 10 pm to 7 am shall not exceed 26°C for more than 1% of annual hours. (Note: 1% of the annual hours between 22:00 and 07:00 for bedrooms is 32 hours, so 33 or more hours above 26 °C will be recorded as a fail)"

Furthermore, the number of successive nights for which the temperature in the main bedroom exceeded the adaptive (or 26oC static) threshold was also determined. Isolated nights of broken sleep are unlikely to have adverse health effects whereas prolonged sleep disruption might. Therefore, as an indicator of the risk of adverse health effects, the number of consecutive nights where the bedroom temperature exceeded the adaptive comfort threshold (and the 26oC static threshold) were also calculated. Sleep was deemed to be unacceptably disrupted if there were three or more successive nights where the temperature exceeded the threshold.

4.1.1 Occurrence of overheating in living rooms and main bedrooms

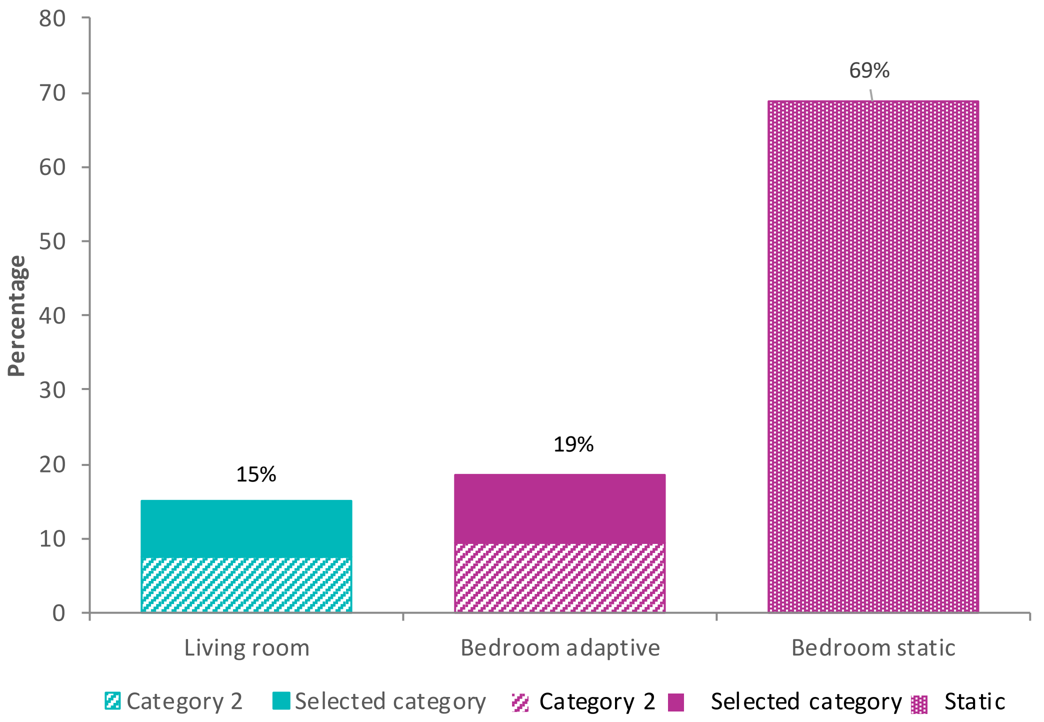
The prevalence of measured overheating across dwelling and socio-economic characteristics, presented in sections 4.1.2 and 4.1.3 of the report focuses on the Selected Category (Sel.Cat.) thresholds unless otherwise stated. However, figures (and the underlying annex tables) also include the results from analyses using only the Cat. II thresholds (patterned bars) as this dual strategy can be useful as a guide to distinguish between the inherent tendency of the dwelling to overheat (Cat. II) and the effect due to the additional heat-sensitivity of vulnerable occupants (Sel. Cat), as the incidence of overheating is notably higher in categories that contain more vulnerable (Cat. I) individuals. It should be noted that the significance level and effect size for tests across groups did show some differences for Cat. II compared with the same analyses performed using the combined Sel. Cat., primarily due to the smaller sample sizes underlying the Cat. II splits, and this should be considered in the interpretation of these results.

The headline results for living rooms revealed that the living rooms in 15% English homes would be classed as overheated; that is, they had more than 3% of assumed occupied hours above the relevant adaptive thermal comfort threshold (either Cat.I or Cat.II depending on occupant vulnerability) (Figure 4.3). The data included some extreme examples, with the hottest monitored living room exceeding the Cat.II threshold for 69% of occupied hours[20].

The headline results for main bedrooms using the adaptive overheating criterion, and either Cat.I or Cat.II depending on household vulnerability, revealed that the main bedrooms in 19% English homes would be classed as overheated (Figure 4.3).

[20] Assessing all homes on the basis that they were occupied by Cat.II households resulted in just 7% of the living rooms and 10% of the bedrooms being classed as overheated. Clearly, the additional sensitivity of vulnerable individuals is pertinent to overheating assessments.

Figure 4.3: Percentage of living rooms and bedrooms in English homes classed as overheated by different overheating criteria



Base: All households with measured temperatures (n=616 living room, n=591 bedroom) Interview 1

Analysis using the static overheating criterion, revealed that 69% of bedrooms in English homes would be classed as overheated; that is, they had more than 32 hours of assumed occupancy with a temperature over 26oC. The hottest monitored bedroom exceeded 26oC for 97% of the occupied hours.

In 22% of homes, the main bedroom overheated (based on the adaptive criterion) for three or more consecutive nights during the summer. Whereas, in 81% of homes the main bedroom exceeded 26oC for three or more consecutive nights.

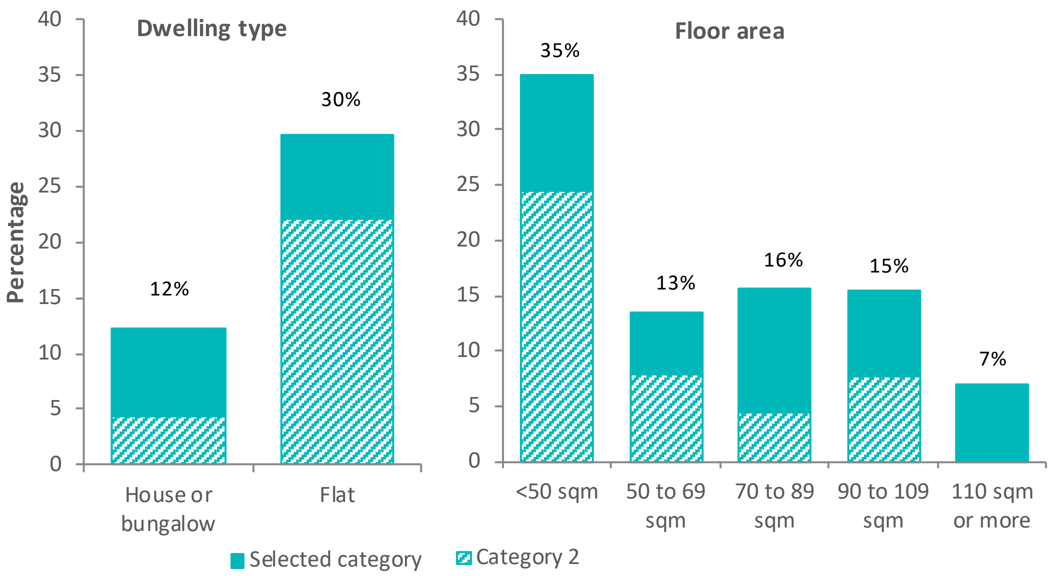
The very high estimates of overheating in bedrooms are far in excess of the incidences of overheating reported by the households themselves (see section 4.2.1). For this reason, and to provide a common basis for comparing living room and bedroom overheating, all further bedroom analyses were, like the living room analyses, undertaken using the adaptive approach.

4.1.2 Measured incidence of living room and main bedroom overheating by dwelling characteristics

Significant differences in the prevalence of measured overheating in the living room by dwelling characteristics were seen for the flat/house split, floor area and region, while in bedrooms differences were only observed by region:

- **Dwelling type** In flats, 30% of the living rooms were overheated compared with 12% in houses (Figure 4.4). Interestingly, the prevalence of overheating in the bedrooms of flats (17%) was not or significantly different from, that in houses (19%)
- **Floor area** In dwellings with a floor area <50m2, 35% of living rooms were overheated compared with 7% to 16% in larger dwellings (depending on floor area). Again, there were no significant differences seen for main bedrooms (Figure 4.4)
- **Region** The prevalence of overheating in living rooms was significantly higher in the London region (28%) compared with the prevalence in all other regions (13%)[21], with a similar pattern seen for main bedrooms (32% for London, 17% for all other regions) at the 95% level

Figure 4.4: Measured incidence of overheating by house/flat and floor area in the living room



Base: All households with measured temperatures (n=616 living room), Interview 1.

There were no significant differences in the measured prevalence of overheating in either the living rooms or the bedrooms for any of the energy efficiency related measures (wall or glazing type, depth of loft insulation, number of energy efficiency measures applied). However, there was indicative evidence to suggest that the prevalence of overheating in living rooms was greater in dwellings with an EPC rating of A to C (21%) compared with dwellings with a D to G rating (13%), although the difference was only significant at the 95% level and was not seen for main bedrooms.

4.1.3 Measured incidence of living room and main bedroom overheating by household characteristics

Across all household categories, overheating in living rooms was most often experienced by households who are amongst societies' most disadvantaged and vulnerable, whereas

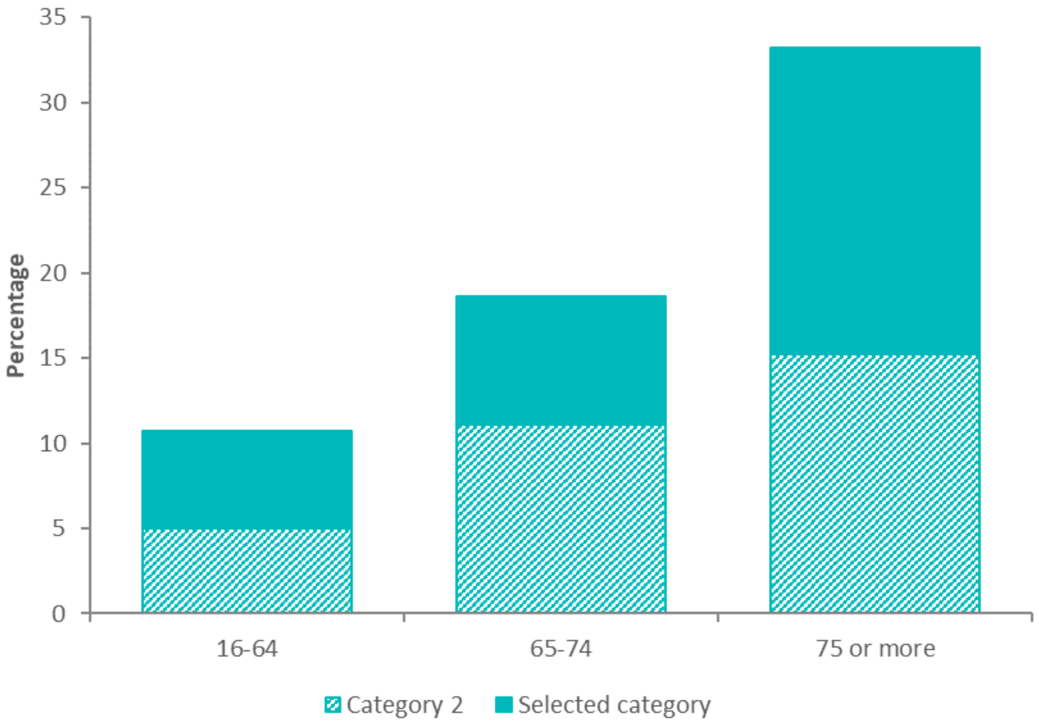
[21] Differences were not significant at the 95% level when the nine regions were analysed but the results indicated a difference existed for the London region. Grouping the other regions together confirmed this finding.

differences in the prevalence of overheating in main bedrooms appeared to be more generally linked to household size.

Analysis by socio-economic characteristics showed that the prevalence of overheating was statistically significantly different across categories for the following groups:

- **Pensioner present and age of HRP** The prevalence of overheating in living rooms was greater in households with a pensioner present (24%) than in those without (11%). The exposure of the elderly to overheating becomes even more pronounced when households are categorised by the age of HRP. The prevalence of overheating in the living rooms of households with an HRP aged 75 or over (33%) was significantly greater than for households where the HRP is aged 65 or younger (11%) (Figure 4.5). This pattern of a higher prevalence of measured overheating in living rooms in households with older occupants was also present in the Cat. II results at the 95% level, suggesting that living rooms occupied by older people are inherently at risk of overheating (Cat.II pattern in Figure 4.5) but that the classification of over 75 year olds as vulnerable (Cat. I.) compounds this risk

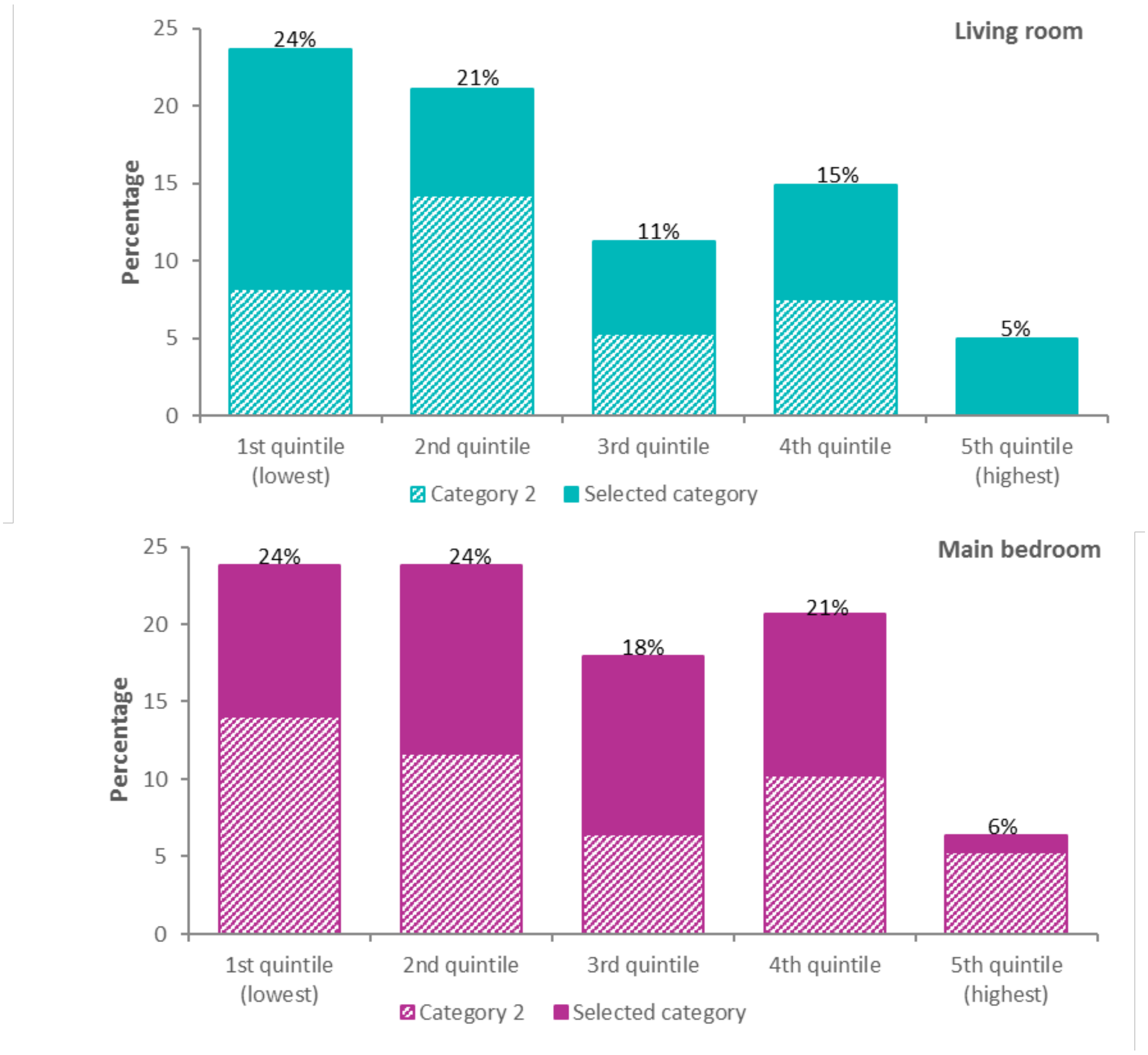
Figure 4.5: Measured incidence of overheating in living rooms by age of HRP



Base: All households with measured temperatures (n=616 living room), Interview 1

Income Households in the lowest two income quintiles had a higher prevalence of overheating in the living room (24% and 21%) compared with those in the highest income quintile (5%). It should be noted that similar differences were also to be found in main bedrooms albeit only at the 95% level (Figure 4.6)

Figure 4.6: Measured incidence of overheating in living rooms and main bedrooms by income quintile



Base: All households with measured temperatures (n=616 living room, n=591 bedroom) Interview 1.

Employment status Households with no-one in employment had a higher prevalence of overheating in the living room (24%) compared with those without (11%); there was evidence of this difference also present in the Cat.II results (at the 95% level), suggesting that this was not driven by the underlying 'vulnerability' of these in a similar way to the results for age of HRP

Long-term sick or disabled Households with someone long-term sick or disabled had a higher prevalence of overheating in the living room (22%) compared with those without (11%), although it should be noted that no difference was present in the Cat. II results indicating that this finding is driven primarily by the lower temperature thresholds assigned to the long-term sick due to their vulnerability. Results at the 95% level indicate a similar trend in the bedroom as well

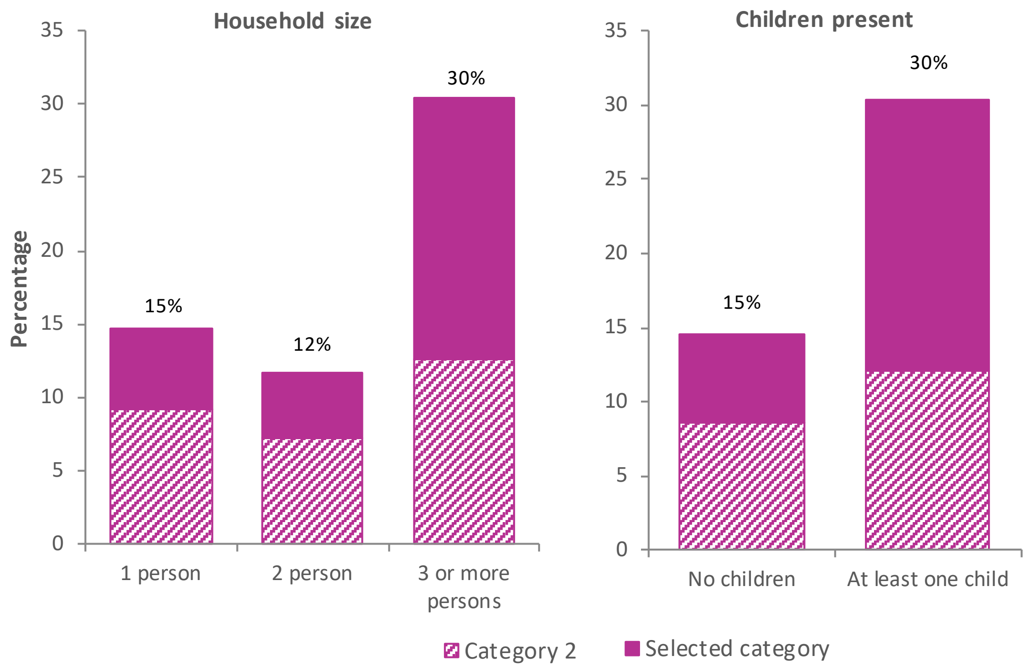
Tenure Households in the social sector had a higher prevalence of overheating, both in the living room and in the main bedroom[22] (26% and 29% respectively) compared with households in the private sector (13% and 17%). The pattern of overheating with tenure prevailed (in both rooms) even when all dwellings were assumed to be occupied by Cat.II households, which indicated that the results were not because social sector dwellings were occupied by more heat-sensitive individuals but rather that they were actually hotter than private sector dwellings

Other socio-economic characteristics showed significant differences in the prevalence of overheating in main bedrooms but not living rooms. These were generally linked to household size:

- **Household size** Larger households had a higher prevalence of overheating in the main bedroom compared with smaller households; 30% of households with 3 or more people overheated compared with 15% of single person households and 12% of two person households. This difference was not seen under the Cat. II criterion, suggesting that the high prevalence of bedroom overheating was because larger households were more likely to include heat-sensitive individuals rather than because the larger number of people induces overheating
- **Children present** Households with at least one child had a higher prevalence of overheating in the main bedroom (30%) compared with households with no children (15%). A similar trend was found for household composition, where couples under 60 with no dependent children had a lower prevalence of overheating (8%) in the main bedroom compared with couples with dependent children (35%) (Figure 4.7)
- **Under-occupancy** Households that were not under-occupying had a higher prevalence of overheating in the main bedroom (22%) compared with households that were under-occupying (11%). This is directly related, by virtue of the definition, to the pattern seen for household size

[22] Significant only at the 95% level for main bedrooms

Figure 4.7: Measured incidence of overheating in the main bedroom by the number of persons in the household and the presence of children



Base: All households with measured temperatures (n=591 bedroom), Interview 1.

4.2 Occupant perception of summer comfort

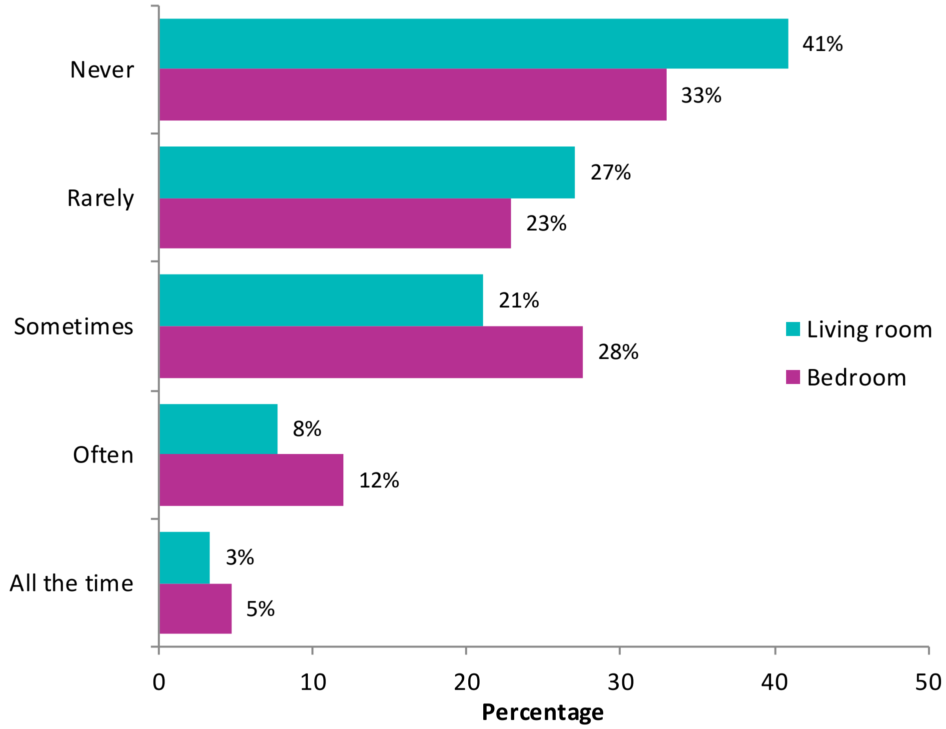
In the Interview 1 survey, the term 'uncomfortably warm' was used to describe a thermal sensation associated with indoor conditions indicative of overheating. Questions were asked probing how often the main living room and main bedroom felt 'uncomfortably warm' in summer (June to August), i.e. were overheated; what the households thought the reasons for the overheating were; and whether any other rooms 'often felt uncomfortably warm'. A household was considered to have experienced overheating where they reported feeling uncomfortably hot 'often' or 'all the time'. The households were also asked about the electrical equipment, if any, that they used to keep cool and how often the equipment was used[23].

4.2.1 Occurrence of overheating in living rooms and main bedrooms

Overall, significantly more households reported feeling uncomfortably warm in the main bedroom compared with the living room. In total, 11% of households (2.5 million) reported living rooms[24] that were uncomfortably warm 'often' or 'all the time' and 17% of households (3.8 million) reported their main bedroom was uncomfortably warm 'often' or 'all the time' (Figure 4.8). In contrast, 41% of households reported that the living room was never uncomfortably warm and 33% that the main bedrooms were never uncomfortably warm.

[23] Annex tables containing the underlying data for this section can be found in Tables_4_2.xls
[24] Analysis of the 'living room' included households with no main bedroom (e.g. bedsits).

Figure 4.8: Reported extent of overheating in living rooms and main bedroom

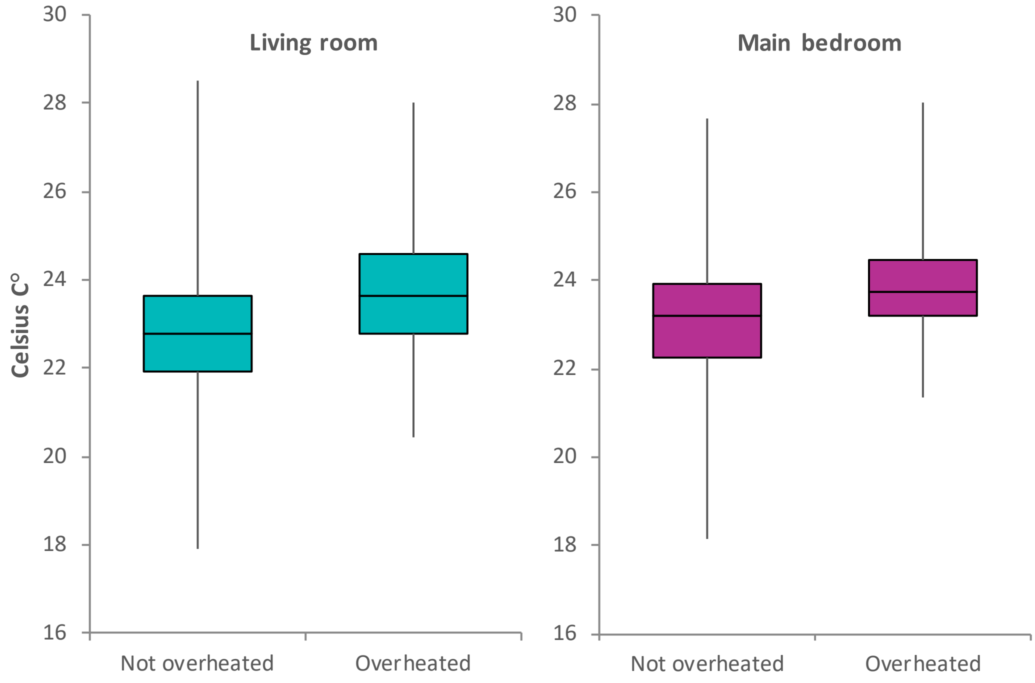


Base: All households (n=2,529 living room, n=2,504 bedroom (excludes bedsits)), Interview 1.

Note: Bedroom total in the figure does not sum to 100% due to rounding

Although the reported overheating results related to the summer of 2017, and the measured internal temperatures were collected in the summer of 2018, it provides some context to note that the mean internal temperatures in both the living room and main bedroom were significantly higher for those households that reported overheating (23.7°C and 23.8°C respectively) compared with households that did not report overheating (22.8°C and 23.1°C respectively). Figure 4.9 shows the minimum and maximum values and the interquartile range of measured 2018 summer temperatures in households that did, and did not, experience overheating in the summer of 2017.

Figure 4.9: Boxplot of mean internal temperatures in the living room and main bedroom by reported overheating (in the respective room)



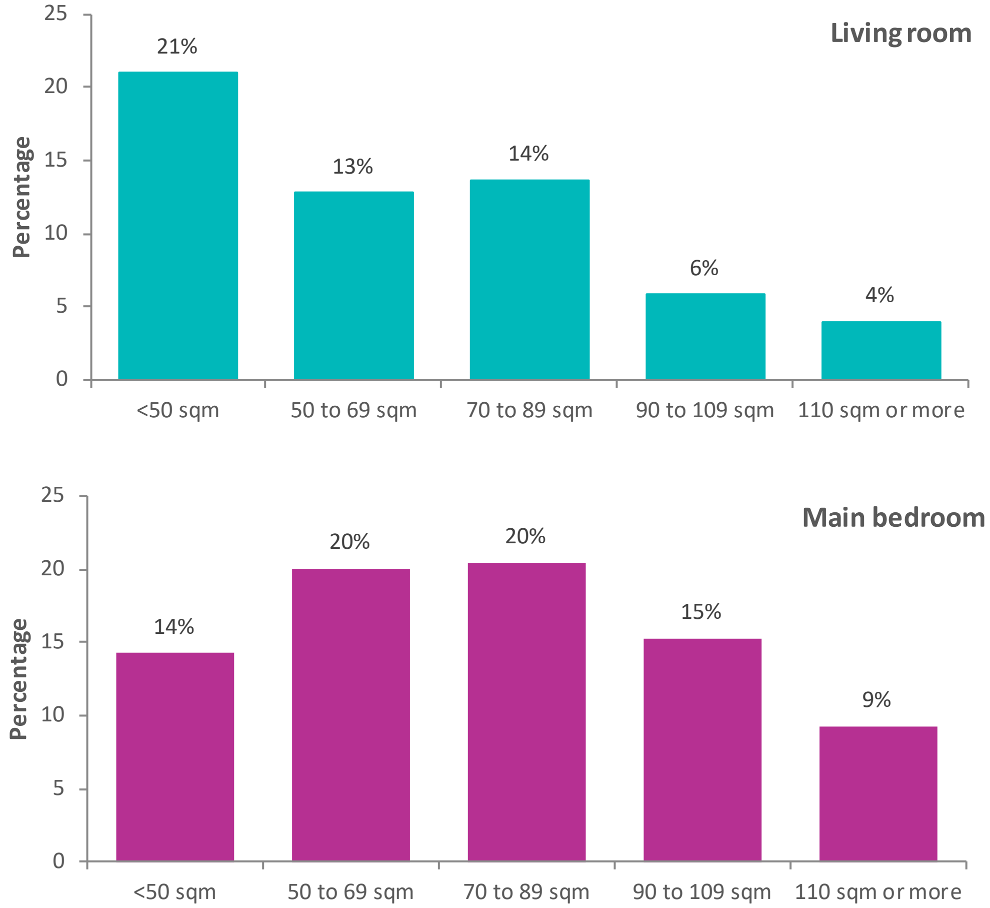
Base: All households (n=651 living room, n=628 bedroom (excludes bedsits)), Interview 1.

4.2.2 Reported incidence of living room and main bedroom overheating by dwelling characteristics

This section examines the characteristics of dwellings occupied by households who experienced overheating (i.e. reported being uncomfortably warm ‘often’ or ‘all the time’). The summary findings are:

- **Floor area** The reported prevalence of overheating in both living rooms and main bedrooms tended to decrease as the dwelling floor area increased. Living rooms in dwellings with a floor area <70m² were reported to overheat significantly more often (13% to 21%, depending on floor area) than the living rooms of larger dwellings (90m² or more; 4% to 6%). The trend was less clear for reported overheating in main bedrooms, although households living in dwellings larger than 110m² were significantly less likely to report overheating (9%) compared with households living in smaller dwellings between 50 and 89m2 (20%) (Figure 4.10)

Figure 4.10: Reported overheating in living rooms and main bedrooms



Base: All households (n=2,529 living room, n=2,504 bedroom (excludes bedsits)), Interview 1.

- **Dwelling type** Reported overheating in living rooms was greater for households living in flats (20%) compared with householding living in houses/bungalows (9%). In particular, households living in detached dwellings were less likely to report overheating in the living room (4%); this was significantly less than that reported by households in flats (20%) and bungalows (13%). For main bedrooms, there was no significant difference in reported overheating between households living in flats and houses, but households living in detached dwellings were less likely to report overheating (10%) compared with all other dwelling types except bungalows (19% to 21%)
- **Region** There was a marked difference in the reported overheating in living rooms between households living in the London region (17%) compared with those living in the other regions (10%), although no regional differences were seen for reported overheating in main bedrooms. There were no significant differences in the reported overheating in either living rooms or main bedrooms between urban and rural areas. The higher prevalence of overheating in London is likely a combination of urban heat island effects, and that a higher proportion of London dwellings are flats

- **Energy efficiency** The prevalence of reported overheating in living rooms increased with the overall energy efficiency of the dwelling; more households reported overheated living rooms in dwellings with an EPC rating A to C (15%) compared with dwellings with an EPC rating D to G (10%). However, homes with an A to C energy rating band were more likely to be flats than homes with poorer energy ratings[25]. There was evidence of a similar pattern in the reported prevalence of overheating in main bedrooms, although the difference was only significant at the 95% level (20% in bands A to C and 15% in bands D to G). Related to this, the reported overheating in living rooms in dwellings heated by non-central heating systems was higher (18%) compared with households living in dwellings with central heating (10%). Households living in dwellings with the least level of loft insulation (<50mm) were more likely to report overheating in their living room (23%) than those households living in dwellings with greater levels of loft insulation (9% to 11%).

4.2.3 Reported incidence of living room and main bedroom overheating by household characteristics

This section examines the socio-economic characteristics of households reporting overheating in the living room and main bedroom. The results are reported for occupants and household representative persons (HRPs) of all age groups, but the self-reporting of overheating by the elderly may not reflect the actual incidence of measured elevated temperatures (see above). The key findings when analysing reported overheating in living rooms and bedrooms by household characteristics are:

- **Tenure** Reported overheating in both living rooms and main bedrooms of owner-occupied dwellings (7% living room; 13% main bedroom) was significantly lower than for all other forms of tenure (16% to 23% for living room; 22% to 25% for main bedroom, depending on tenure category), perhaps reflecting the higher prevalence of houses and larger dwellings, or the increased prevalence of older occupants within this tenure (Figure 4.11). This corresponds with the measured mean living room internal temperatures in summer being significantly lower for owner-occupied dwellings (22.8°C) compared with local authority dwellings (23.6°C), although there was no significant difference in the bedroom temperatures between owner occupiers and other tenures

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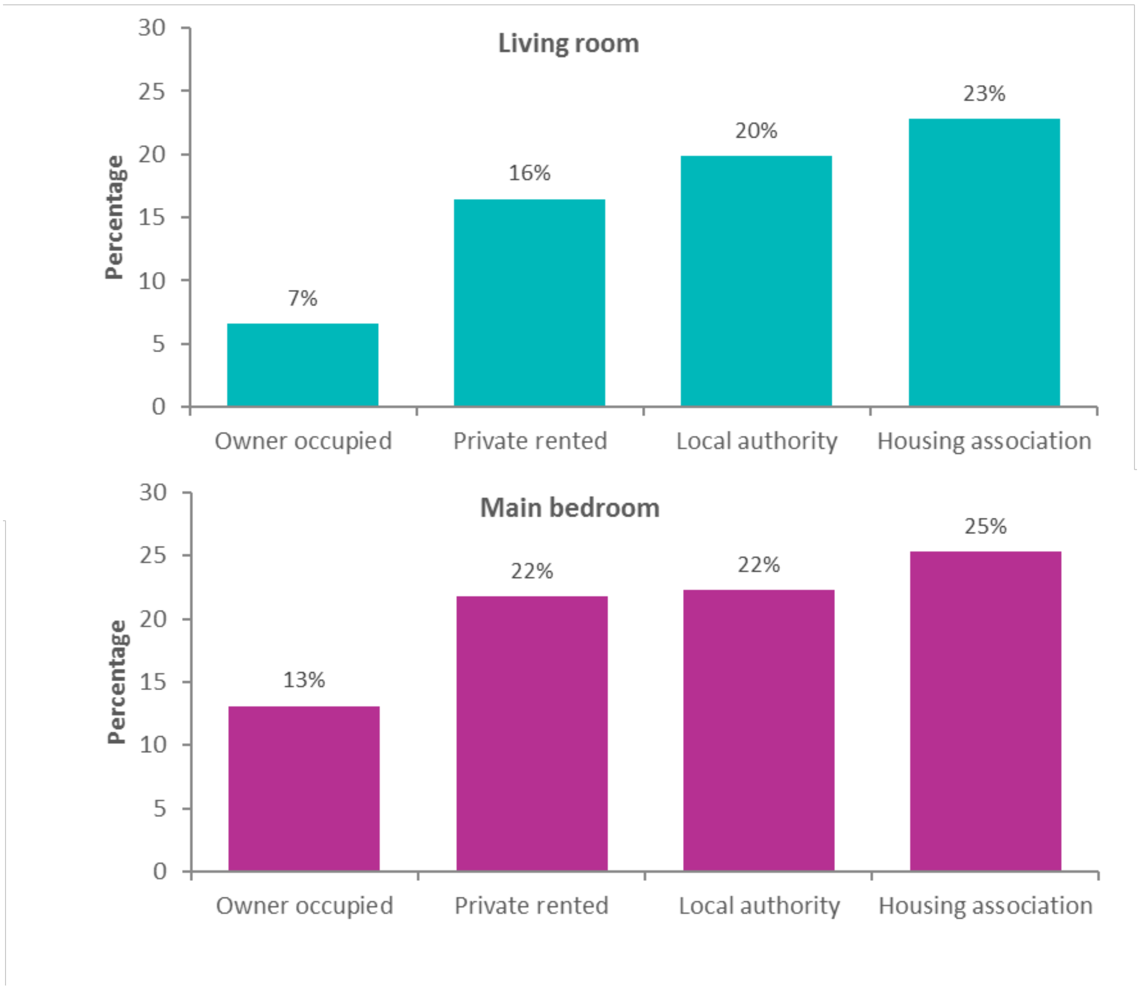
[25] EHS Live Tables, DA7101: energy performance – dwellings, https://www.gov.uk/government/statistical-data-sets/energy-inefficient-dwellings

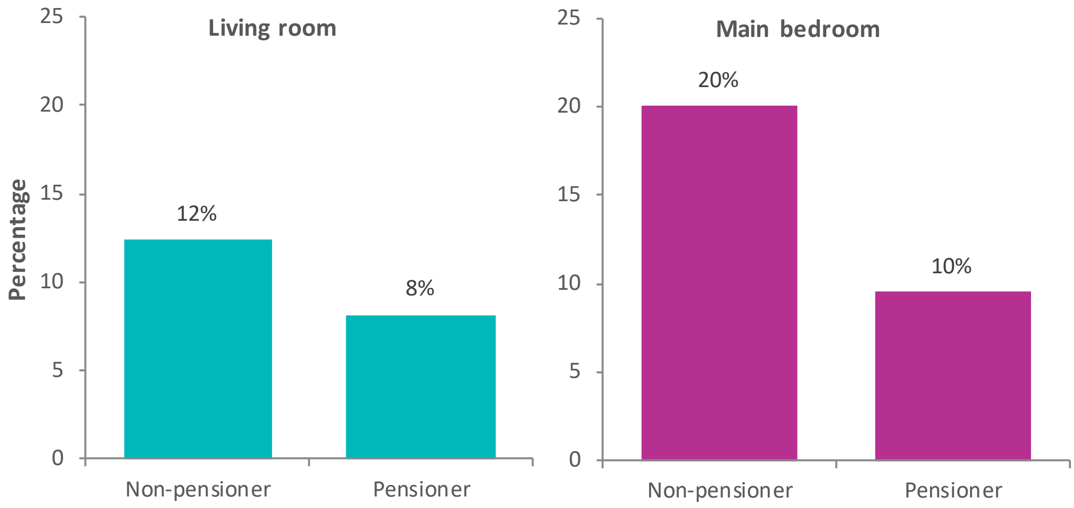
Figure 4.11: Reported overheating in living rooms and main bedrooms by tenure



Base: All households (n=2,529 living room, n=2,504 bedroom (excludes bedsits)), Interview 1.

- **Household composition** The reported prevalence of overheating in living rooms was less in households comprising a couple over 60 years (6%) compared with households comprising lone parent with dependent children (16%). For bedrooms, both single person households over 60 years (8%) and couples over 60 years (11%) were less likely to report overheating in the main bedroom compared with households with lone parents and dependent children (25% bedroom)
- **Pensioner present** Pensioner households, or households over 65 years, were less likely to report overheating in both the living room (8%) and main bedroom (10%) compared with non-pensioner households (12% living room, 20% bedroom respectively) (Figure 4.12)

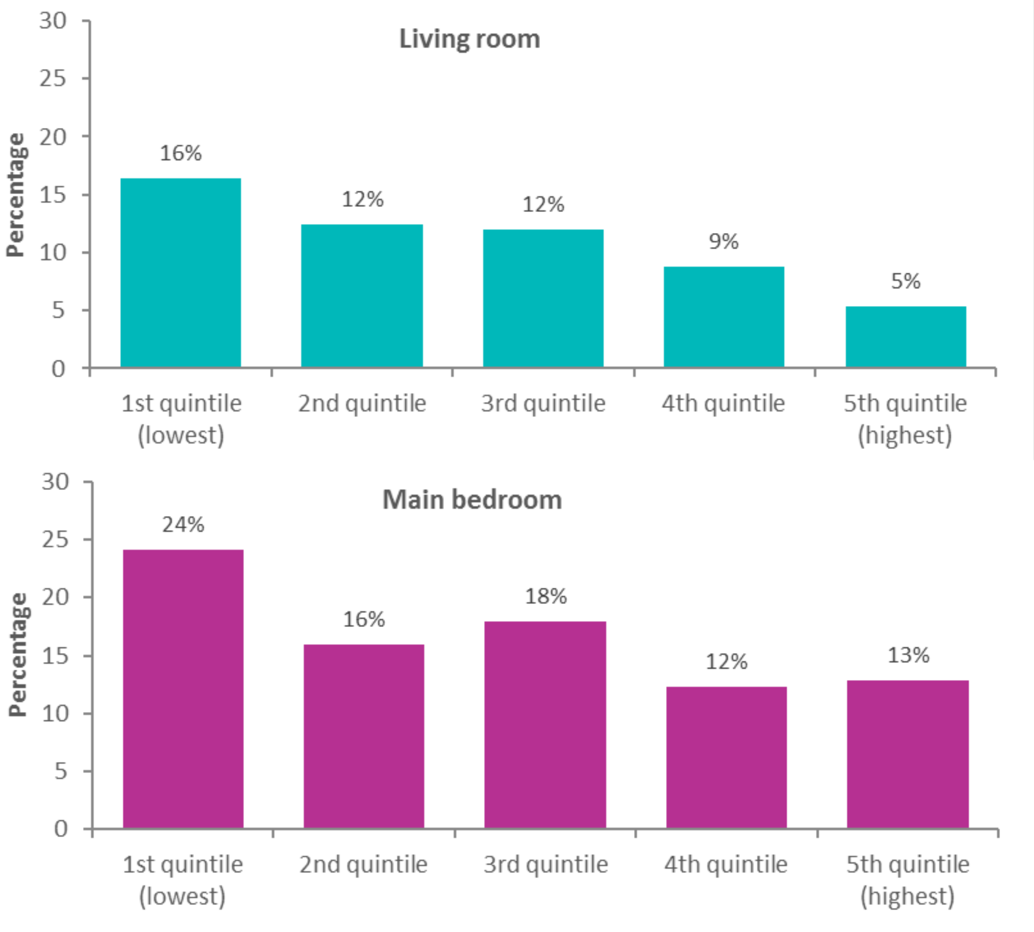
Figure 4.12: Reported overheating in living rooms and main bedrooms by pensioner present



Base: All households (n=2,529 living room, n=2,504 bedroom (excludes bedsits)), Interview 1.

Income Households in the lowest income quintile were significantly more likely to report overheating in living rooms (16%) and main bedrooms (24%) compared with households in the two highest quintiles (9% and 5% living rooms; 12% and 13% main bedrooms) (Figure 4.13)

Figure 4.13: Reported overheating in living rooms and main bedrooms by income quintiles



Base: All households (n=2529 living room, n=2504 bedroom (excludes bedsits)), Interview 1.

- **Under-occupancy** Reported overheating in both the living room and the main bedroom were also significantly lower in homes where the household was under-occupying (5% living room; 11% main bedroom) compared with those not under-occupying (13% living room; 19% bedroom)

The following socio-economic characteristics showed differences in the reported prevalence of overheating in main bedrooms only:

- **Age of HRP** Results indicated that reported overheating in the main bedroom decreased as the age of the HRP increased. Reported overheating in the main bedroom was significantly less in households where the HRP was 65 or older (8% to 10%) compared with those where the HRP was less than 45 years old (20% aged 35-44, 27% aged 16-34)
- **Children present** Households with one or more children were significantly more likely to report overheating in the main bedroom (25%) compared with households without any children (14%)
- **Household size** The prevalence of reported overheating in the main bedroom increased as the size of the household increased. Reported overheating in the main

bedroom was less likely to be reported by households with one or two persons (13%, one person, 16% two persons) than by households with three or more persons (21%).

- **Employment status** Bedrooms were less frequently reported as overheating in households where no one was employed (including retired) (14%) compared with households in employment (18%)

There was no clear pattern or significance in the results for either room when looking at fuel poverty status, or long-term health and disability status.

4.2.4 Multivariate Analysis

As reported in section 4.2.1, 11% of households reported overheating in their living room (the dependant variable in the modelling) during the summer and 17% reported overheating in their main bedroom.

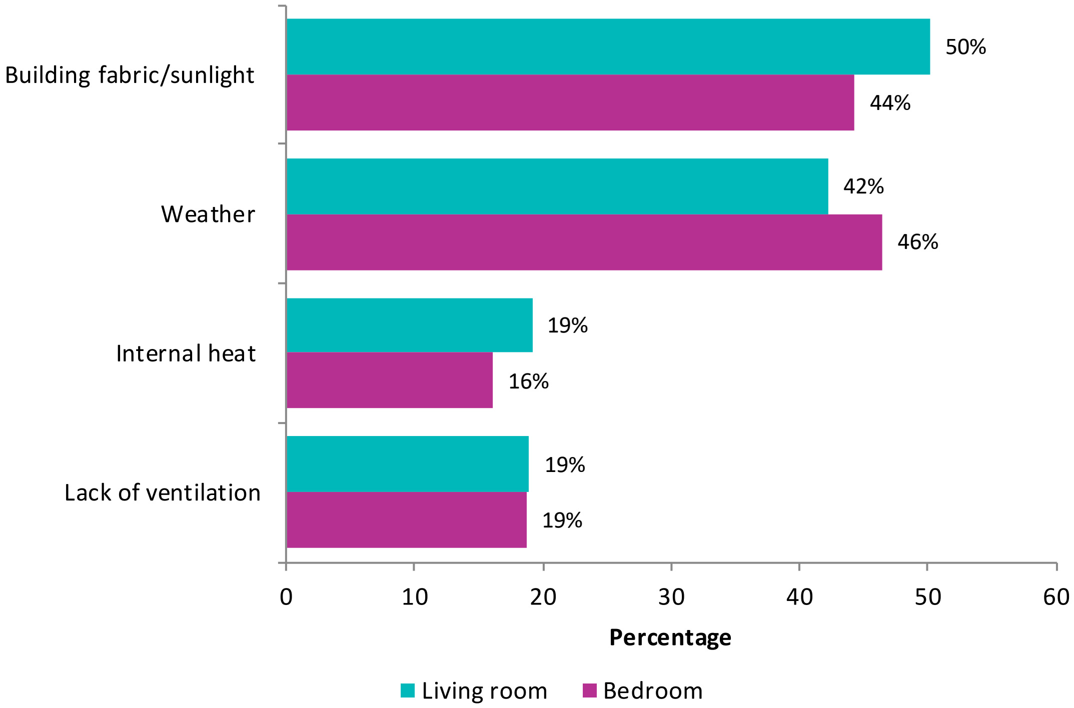
Overall, it was found that no subset of the variables (households and dwelling characteristics) used in this analysis made a good model for predicting whether a household self-reported overheating in their living room, or main bedroom, and so the main reason(s) why households report overheating in the room are unclear.

4.2.5 Reasons for overheating

Those households who reported feeling uncomfortable warm, for any amount of time[26], in their living room or in their bedroom were asked about the reasons for this. Respondents were able to choose as many answers or as few as applied. One reason offered was ‘No reason other than unusually high temperatures outside’; all those selecting this reason also gave other reasons, suggesting that high external temperatures were an exacerbating factor. The reasons reported have been grouped into four main categories; unusually warm external weather[27], issues to do with the building fabric (e.g. thin walls) or lack of shading from sunlight, internal heat gains (e.g. from the boiler or cooking or from other flats) and problems with a lack of ventilation. The most common factors underlying overheating in both rooms were those relating to the external weather and the building fabric/sunlight; while around one-fifth of households reported that internal heat gains or lack of ventilation were the causes (Figure 4.14).

[26] The question was asked of households who reported feeling uncomfortably warm either all the time, often, sometimes or rarely.
[27] This includes the reason ‘respondent feels warm’, for which there were only 4 responses.

Figure 4.14: Reported reasons for overheating



Base: All households with a reason for reporting feeling uncomfortably warm (n=1,362 living room, n=1,539 bedroom (excludes bedsits)), Interview 1.

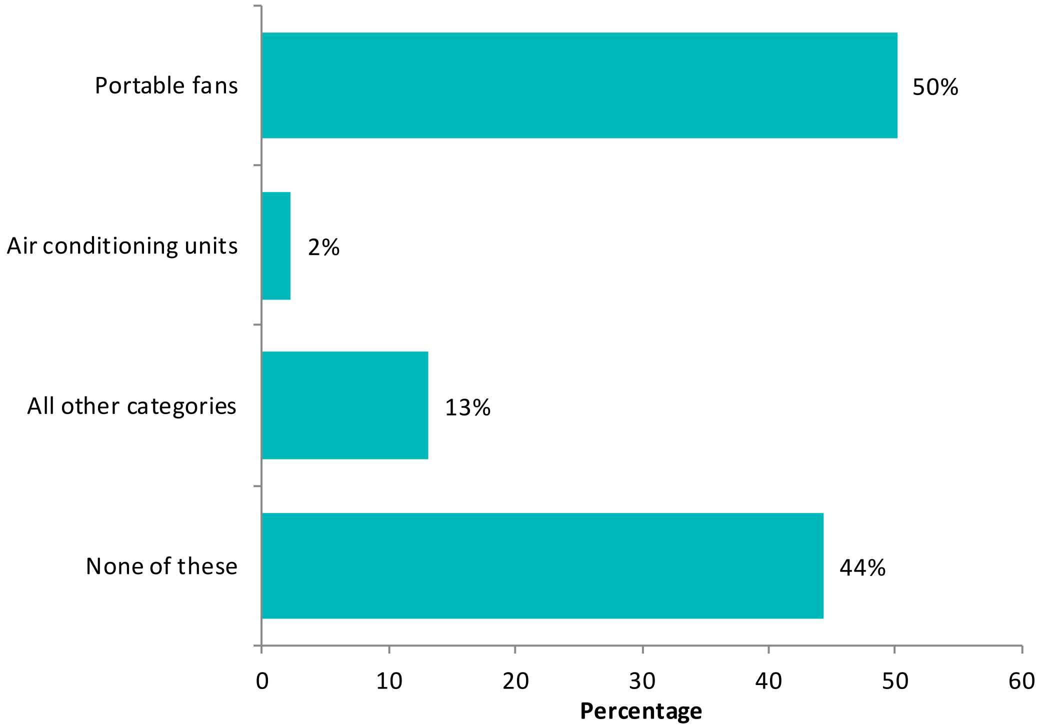
4.2.6 Overheating in other rooms

The wider extent of perceived overheating was investigated by asking 'Other than the living room and main bedroom, which, if any, of the other rooms in your house are often uncomfortably warm in summer?'. Almost 60% of households reported that no other rooms felt uncomfortably warm. Overheating in another bedroom was reported by 20% of households. Although kitchens and kitchen diners were reported as overheated by 17% of households, i.e. more often than the main living room (11%), heat from cooking may be a contributory factor. Overheating in other rooms was infrequently reported (<5% of households).

4.2.7 Use of electrical cooling equipment

All households were asked to specify what electrical cooling system, if any, they used to help cool their home. Many households (44%), used no cooling equipment at all, however half of households (50%) reported using portable fans. Other cooling equipment (including fixed fans, extractor fans, dehumidifiers and humidifiers) were used by 13% of households, while just 2% of households reported using a fixed or portable air conditioning unit (Figure 4.15).

Figure 4.15: Reported use of electrical cooling equipment



Base: All households (2,592), Interview 1.

For each item of cooling equipment used, households were then asked how often each item was used in a typical summer. In households that used portable fans, they were used frequently ('often' or 'all the time') by 33% of respondents. Although few households used portable air conditioning units, when present they were used often or all the time in 44% of these households.

4.3 Comparison between measured and perceived/reported overheating

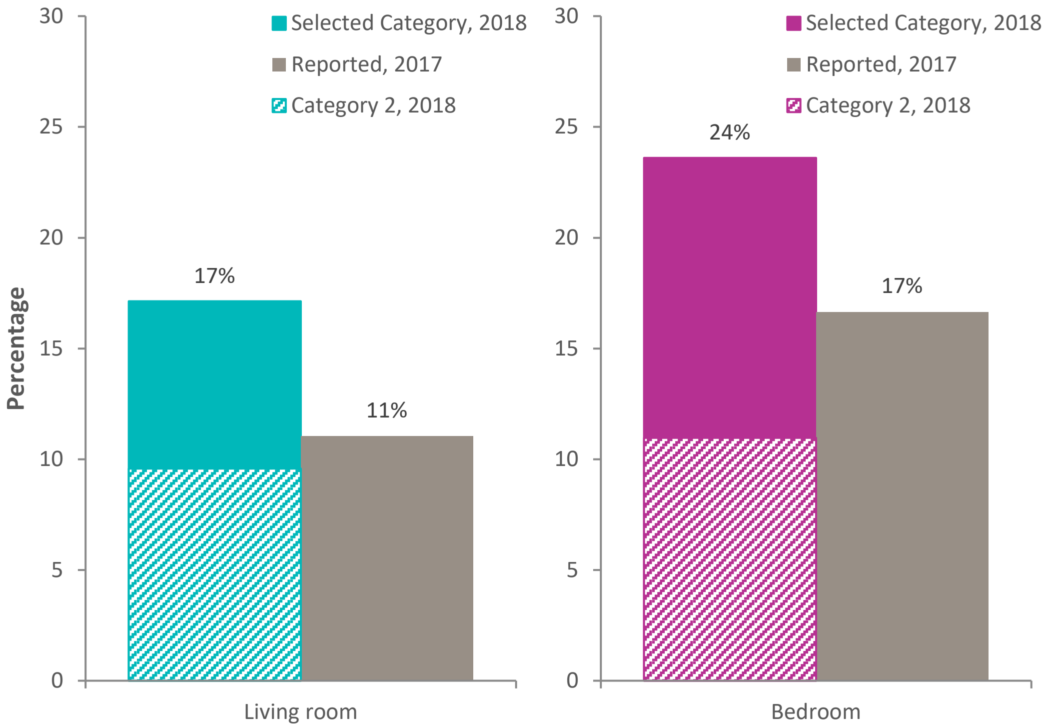
It has been shown that the prevalence of overheating changes with dwelling and household characteristics (sections 4.1 and 4.2, respectively). If such changes are inherent to the dwelling and household, then one would expect these patterns of overheating, for example less overheating as the floor area increases or as the household size decreases, to be preserved irrespective of the method of assessment or the year of assessment. Of course, the absolute prevalence of overheating will change depending on the year and, quite probably, with the method of assessment, but if the patterns are robust and inherent features of the English housing stock they should endure.

To test whether this was indeed the case, each pattern of self-reported overheating during the summer of 2017 is compared with the corresponding pattern based on temperature monitoring during 2018. The only change from the analysis above (section 4.1) is that the prevalence of measured overheating in 2018 was based on temperatures recorded in the summer (June to

August), rather than between May and September[28]. This was done to match with the period for which households reported overheating[29],[30],[31].

Overall, living rooms were reported as overheated, i.e. uncomfortably warm 'often' or 'all the time' in 2017, by 11% of households, compared with the 17% classed as overheated based on the summertime measurements in 2018 (Figure 4.16). Bedrooms were reported as uncomfortably warm 'often' or 'all the time, i.e. overheated, by 17%, compared with the 24% deemed to be overheated based on the measurements. The interesting points are that both the measured and self-reported incidences of overheating were of similar magnitude, and that for both the measured and self-reported overheating, the prevalence of overheating in bedrooms was greater, on average, than in living rooms.

Figure 4.16: Comparison of measured and self-reported overheating for all households, in the living room and main bedroom



Base: All households with measured temperatures (n=645 living room, n=620 bedroom and all households (n=2,592 living room; n=2,504 bedroom (excludes bedsits)), Interview 1

In the main bedrooms, the prevalence of self-reported overheating in 2017 (17%) was much lower than the level of measured overheating in 2018 as judged by the static (26oC) overheating criterion (69%). Although the years differ, this adds further weight to the

[28] The percentage of hours of overheating in the summertime is, of course, greater than during the longer May to September period. Thus, the absolute monitored prevalence values are higher in this section than in section 4.1.
[29] The interview questions for overheating specified a "typical summer (June to August)".
[30] In fact, the same patterns in the monitored overheating with dwelling and household characteristics were seen for both the September-May and June-August analysis although there are some instances in which differences with category were significant at the 95% level rather the 99% level.
[31] Annex tables containing the underlying data for this section can be found in Tables_4_3.xls.

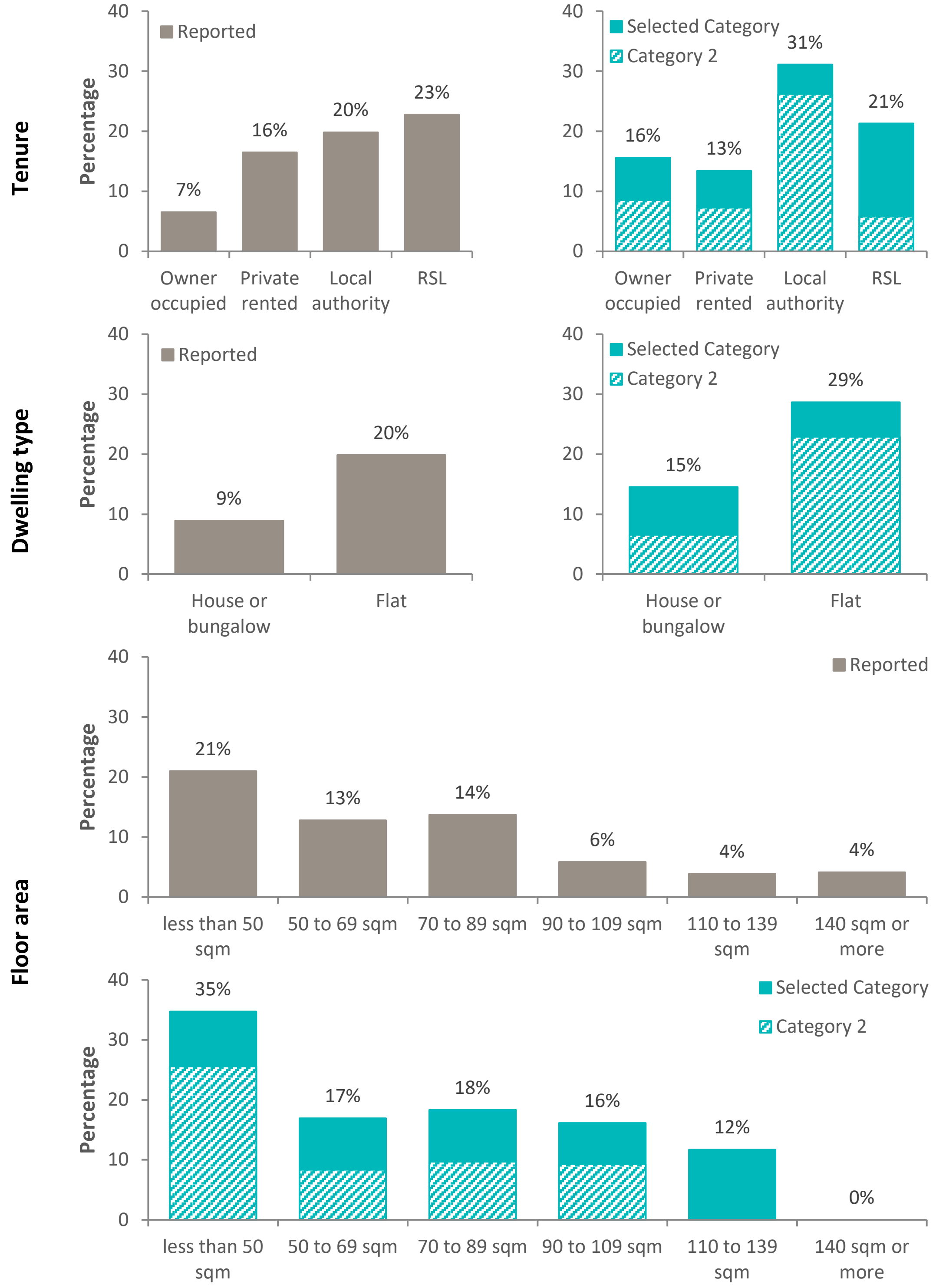
proposition made above (section 4.1.1) that the adaptive overheating criterion provides a better reflection of the occupant's 'experience' of bedroom temperatures than the static criterion.

Concerning the patterns of overheating, there were strong similarities between the self-reported and measured patterns for each dwelling characteristic. In fact, for both the rooms (bedroom or living room) where there were significant differences in the measured overheating with dwelling characteristic, there were also significant differences in the reported overheating. Conversely, where no significant differences were revealed by the measurements there were no significant differences in the self-reports. The same similarity of patterns and agreements in significance was also observed for the household characteristics, but with the important exception of those characteristics related to the age of the occupants[32].

In living rooms, both the measured and reported overheating was significantly higher in flats compared with houses, smaller dwellings compared with larger, households with low incomes compared with those on higher incomes, and households in the social sector compared with those in private tenures (Figure 4.17 and Figure 4.18). Although both measured and reported overheating saw a significantly higher prevalence of overheating in dwellings located in the London region, compared with other regions, the analysis of measured overheating for the June to August period did not show a significant regional difference. There was also a higher prevalence of overheating in the living rooms of more energy efficient dwellings (SAP rating A to C) than in less energy efficient homes (rated D to G) but this may be because there was a significantly higher proportion of flats in the more energy efficient group.

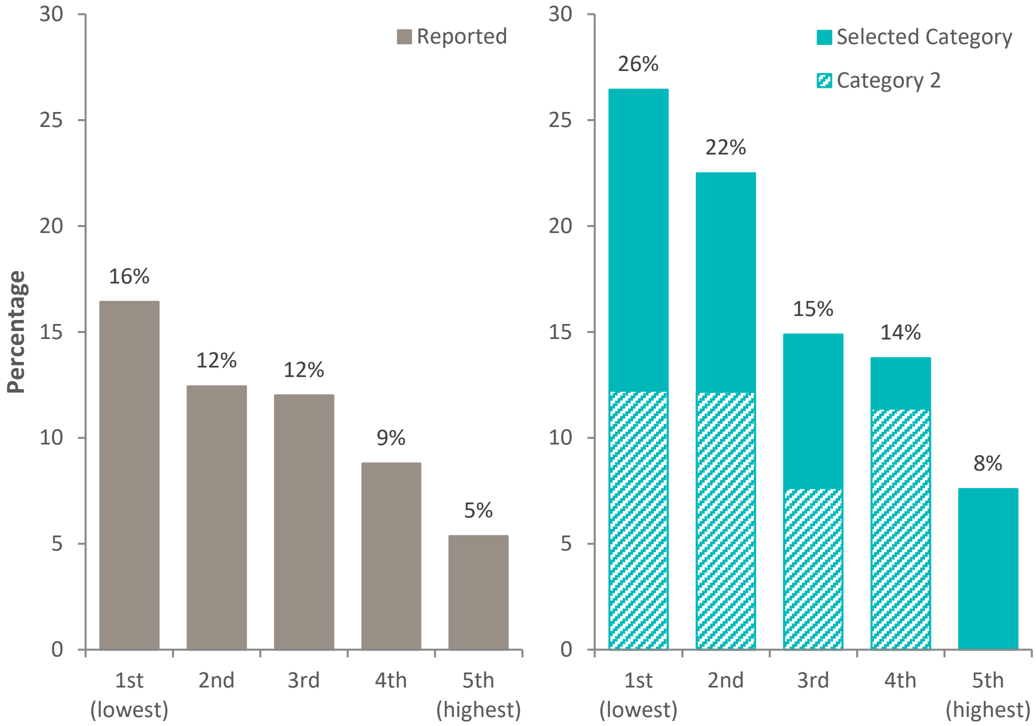
[32] Age of HRP, but also, for example, household composition, under-occupancy, presence of occupants of pensionable age, employment status.

Figure 4.17: Measured and self-reported overheating in the living room by tenure, dwelling type and floor area



Base: All households with measured temperatures (n=645 living room) and all households (n=2529 living room), Interview 1.

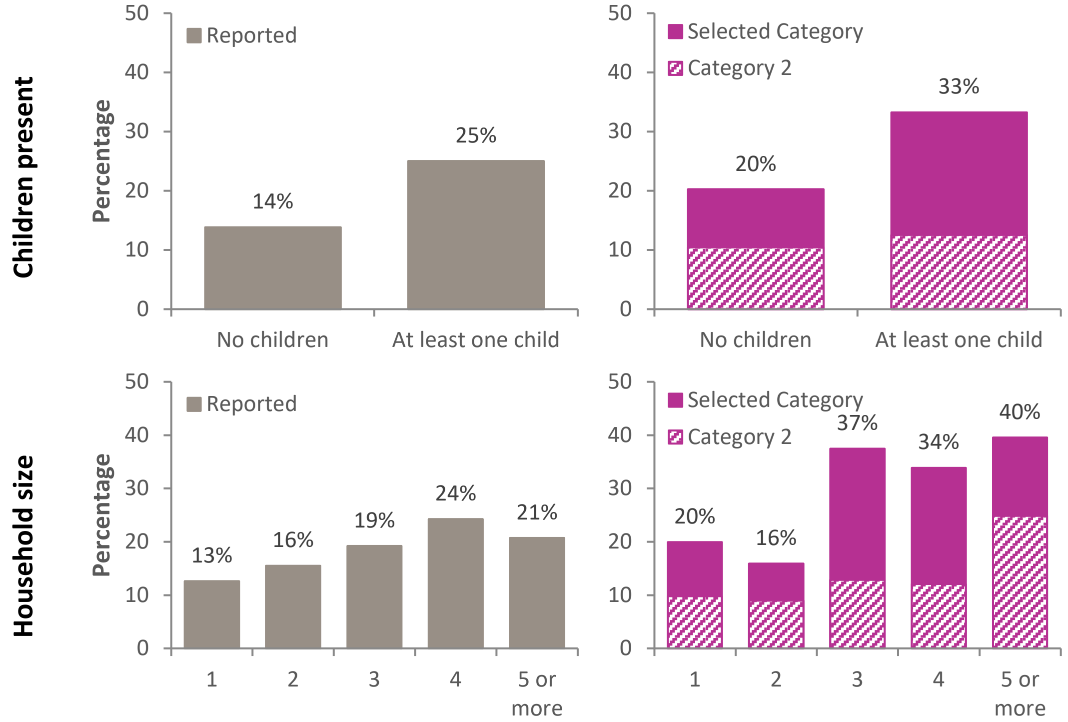
Figure 4.18: Measured and self-reported overheating in the living room by income quintiles



Base: All households with measured temperatures (n=645 living rooms) and all households (n=2529 living rooms), Interview 1.

In main bedrooms, both measured and reported overheating was significantly higher in households with greater number of occupants and households with children present (Figure 4.19)

Figure 4.19: Measured and self-reported over heating in the bedroom by household size and children present



Base: All households with measured temperatures (n=620 bedroom), and all households (n=2504 bedroom (excludes bedsits)), Interview 1.

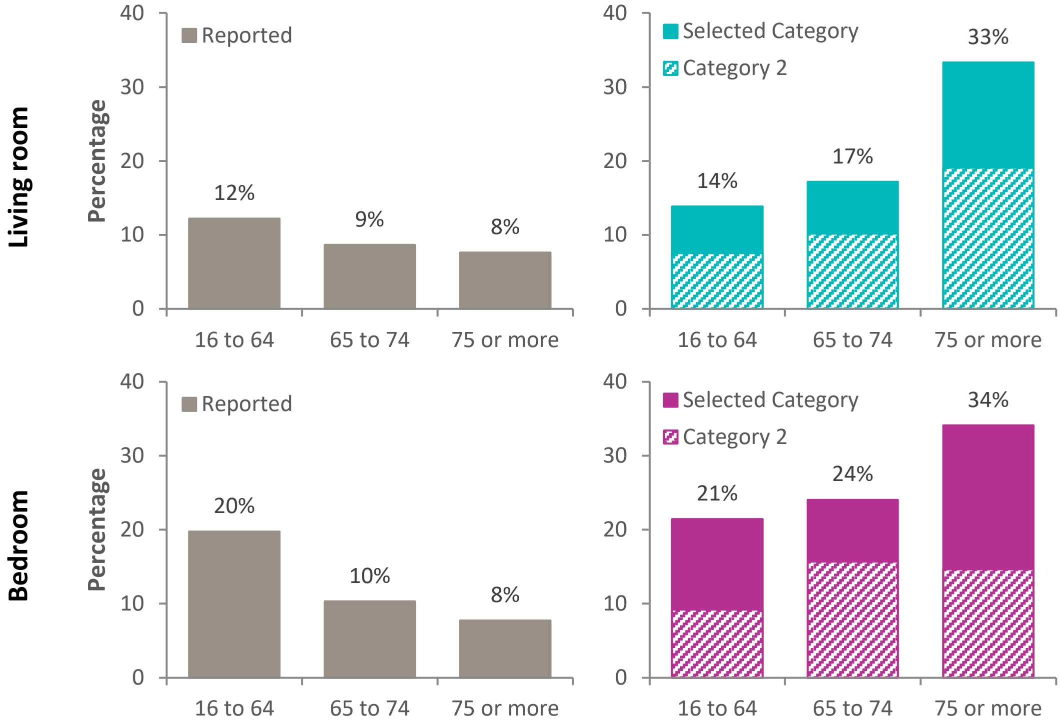
Households with someone long-term sick or disabled had a higher measured prevalence of overheating in living rooms and bedrooms but this wasn't seen in the self-reported data[33]

For household characteristics which are related to the age of the occupants there were some clear differences between the patterns of measured and reported overheating. Perhaps the most important observation, and one that has major implications for the conduct of overheating trials, is the stark difference between the patterns of measured and self-reported overheating in homes occupied by older people.

The measured prevalence of overheating in the living rooms of homes with a pensioner present was significantly greater than in other households, markedly so in the case of households where the HRP was aged 75 or more, compared with households where the HRP was younger than 75[34] (Figure 4.20). However, the self-reported prevalence of overheating in the living room was significantly lower for households with a pensioner present. Similarly, the self-reported overheating in bedrooms of homes with pensioners was significantly less than in homes occupied by those less than pension age whereas no difference was observed for measured overheating.

[33] As discussed in section 4.1.3 this result was a function of the Sel.Cat. methodology
[34] Significant at the 95% level for pensioners, June-August

Figure 4.20: Comparison of measured and self-reported incidence of overheating by age of household representative person



Base: All households with measured temperatures (n=645 living room, n=620 bedroom) and all households (n=2,529 living room, n=2,504 bedroom (excludes bedsits)), Interview 1.

These results support the general proposition that older people tend to under-report overheating. As noted above (Section 4.2.3), older people are poor detectors of temperature, and they may also prefer higher temperatures. Older people can also be more seriously affected by elevated temperatures than younger people.

Future overheating studies based on self-reporting need to be conducted with extreme care. They may prove unreliable in the assessment of the risks to health from high temperatures, especially in the case of older people who are actually amongst the most vulnerable to heat.

4.4 Overheating during a period of exceptionally hot weather

To explore how households dealt with the most extreme hot external temperatures, the hottest week during the temperature monitoring period was analysed in more detail. The hottest week occurred from Monday 23rd July 2018 to Sunday 29th of July 2018. It was the joint second warmest July recorded since 1910 and a maximum temperature of 35.3°C was recorded at Faversham (Kent) on the 26th July; temperatures dropped sharply on July 28th following a thundery breakdown across much of the country on the 27th July[35].

[35] Annex tables containing the underlying data for this section can be found in Tables_4_4.xls

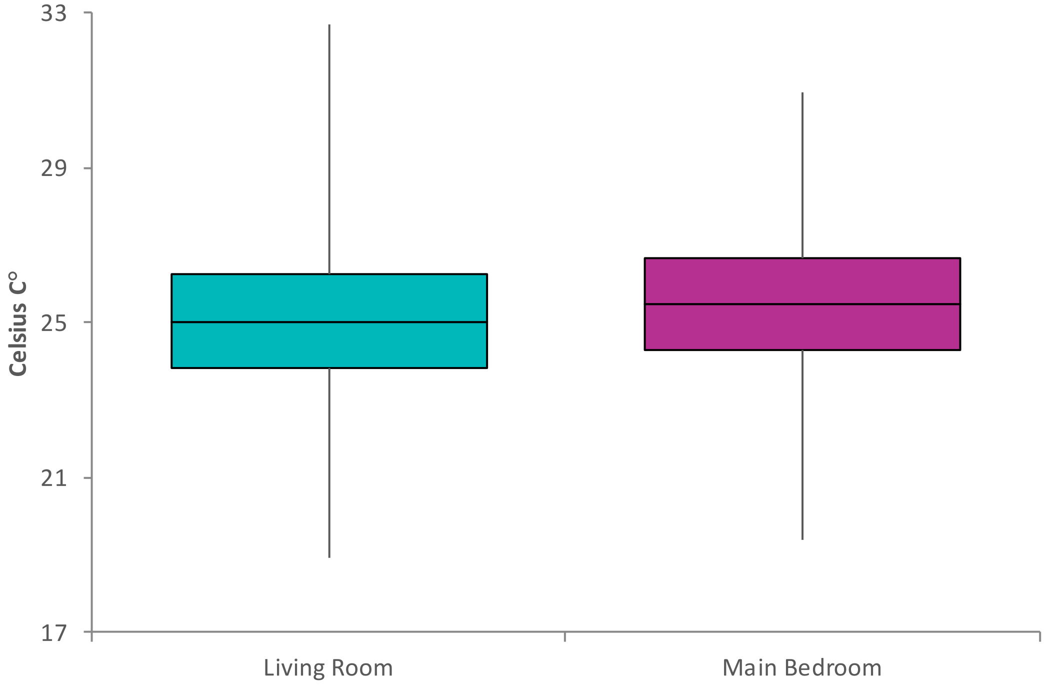
Analysis of the measured internal temperatures for this week showed that bedrooms were, on average, about 0.5°C hotter than living rooms (Figure 4.21). The warmest 20% of households had a weekly averaged living room temperature above 26.5°C and in the main bedroom the warmest 20% of households had a weekly averaged temperature above 26.9°C, a temperature that could be considered uncomfortable to sleep in. However, it should be noted that this analysis was not able to account for householders on holiday, and not occupying the dwelling for whatever reason at that time.

A text message spot survey was delivered on Friday 29th June 2018. Four questions were asked, with multiple answers offered for each one. They covered the thermal sensation experienced in the living room during the past few days, the presence or not of a cool place that would act as a safe-haven from the heat, the use of electric cooling devices and disruption to sleep.

Uncomfortably hot conditions in the living room over the preceding few days were reported by 38% of households responding to this text message survey[36]. Of these, 63 households (47%), had a cool place to go when they felt hot, 53% did not. In the whole text-survey sample, 45% of households did not have a cool place to go as respite from the heat. Around half (46%) of respondents said they had used an electric device to keep cool during the past few days. Some 71% of respondents had found it difficult to sleep on one or more nights. This is important because disrupted sleep can have a detrimental effect on health and wellbeing.

[36] Due to the small sample size of households responding to the text survey, the results presented are unweighted and are therefore not representative of the national level. The results do, however, provide a useful snapshot of households' experiences during a period of exceptionally hot weather.

Figure 4.21: Mean internal temperatures in the living room and main bedroom during the hottest week



Base: All households (n=691 living room, n=672 bedroom), Interview 1.

5. Winter thermal comfort

This chapter explores householder perceptions of thermal comfort over the winter season, the frequency of discomfort in different rooms and the perceived causes of the thermal discomfort. It summarises the findings of bivariate and multivariate analysis investigating how the levels of discomfort varied by different dwelling and household characteristics, including fuel poverty status. The analysis is primarily based on data collected from the Interview 2 survey and, therefore, temperatures measured in the winter 2017/2018 period (see Section 3.2 for a summary of the measured internal temperatures for this time period). For context, an overview of the variation in the measured mean internal temperatures in the living room and main bedroom by dwelling and socio-economic characteristics are presented first.

5.1 Living room and main bedroom internal temperatures in winter

Analysis of mean internal temperatures within the living room and main bedroom have been analysed by dwelling characteristics[37]. The following significant differences were observed for the 2017/18 winter period, with similar results observed for the living room and main bedroom:

- **Dwelling age** Households in the oldest pre-1919 dwellings were significantly colder in the living room and main bedroom than newer dwellings, with the largest difference observed between pre-1919 (living room 17.7°C) and post-1990 dwellings (living room 19.1°C)
- **Energy efficiency rating** The EPC rating had a large impact on the mean internal temperatures in the living room and main bedroom. The living room mean temperature was significantly colder in F and G rated properties (living room 17.2°C), compared with A to C and D rated properties (living room 18.6°C to 19.3°C). A stronger effect was seen for bedroom temperatures, again with significantly colder temperatures in F and G rated properties (bedroom 15.7°C) compared with all other properties (bedroom 17.8°C to 18.9°C). Analysis of the gas meter point data showed that the median annual gas consumption in dwellings rated A to C was 9,600 kWh/year, significantly lower than the median of 13,000 kWh/year used in D rated dwellings and 14,500 kWh/year used in E rated dwellings
- **Insulation measures** Similar to the EPC rating, households with no insulation measures (living room 17.5°C, bedroom 17.1°C) were found to be significantly colder in the living room and bedroom than households with two or more insulation measures (living room 18.8°C to 19°C, bedroom 18.5° to 18.6°C)

Additional results were found for living rooms and bedrooms separately:

- **Dwelling type** Living rooms were significantly colder in houses (living room 18.5°C) than in flats (19.5°C), however no difference was observed in the bedroom temperatures
- **Rurality** Bedrooms were significantly colder in rural dwellings (bedroom 17°C) compared with urban dwellings (bedroom 18.4°C), however no difference was observed in the living room temperatures
- **Main heating system** Bedrooms were significantly colder in households with non-central heating systems (bedroom 17.2°C) compared with households with central heating (bedroom 18.3°C)

In addition to the above, there were significant differences by separate insulation measures (wall insulation and double glazing). At the 95% level there was an indication of significant differences in bedroom temperatures by region. No significant differences were observed for

[37] Annex tables containing the underlying data for this section can be found in Tables_5_1.xls

mean internal temperatures in the living room or bedroom by floor area or main heating fuel type.

Analysis of mean internal temperatures within the living room and main bedroom have also been analysed by socio-economic characteristics. No significant differences (at the 99% level) were observed for temperatures in the main bedroom, however the following significant differences were observed for the 2017/18 winter period in the living room:

- **Age of HRP** Younger households were colder than older households, with the largest difference in mean living room temperatures observed between households where the age of the HRP is between 16 to 34 (living room 18.4°C) and households where the HRP is 75 or older (living room 19.8°C)
- **Presence of pensioner** Similar to above, households without a pensioner present (living room 18.4°C) were colder than households with a pensioner (living room 19.3°C). This likely reflects that pensioner households were more likely to have someone at home during the day (63%) than non-pensioner households (34%), and on average had their main heating on for longer (9hrs:00mins) compared with non-pensioner households (6hrs:15mins) in their living room[38]
- **Income** Results showed the coldest living room temperatures in the highest income households (living room 18.1°C), and the warmest living room temperatures in households in the second income quintile (living room 19.5°C). This finding likely reflects the different distribution of dwelling ages and types of homes occupied by each income group and may also be influenced by household occupancy patterns as households in the lowest two income quintiles were more likely to be in during the day compared with higher income households[39]

In addition to the above, at the 95% level, there was indication of significant differences in the living room temperatures by: household composition, tenure, households where someone has a long-term sickness or disability, under-occupancy, and the employment status of households. For bedrooms, at the 95% level there was an indication of significantly colder bedrooms in under-occupying households only. There were no significant differences, in either room, by household size, the presence of children in the household or fuel poverty status.

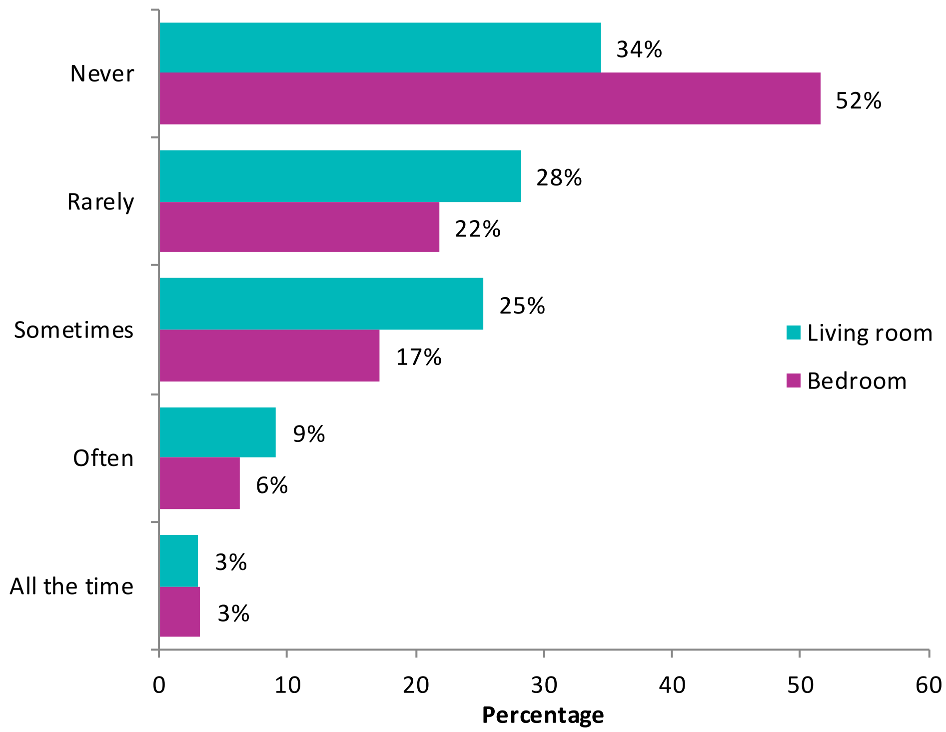
5.2 Reported winter thermal comfort in the living room and main bedroom

In Interview survey 2, householders were asked ‘This Winter, how often has the living room felt uncomfortably cold?’ and ‘This Winter, how often has the main bedroom felt uncomfortably cold?’[40]. Overall, 12% of households (2.9 million) reported living rooms that were uncomfortably cold ‘often’ or ‘all the time’ and 9% of households (2.2 million) reported their main bedroom was uncomfortably cold ‘often’ or ‘all the time’ (Figure 5.1). In contrast, 34% of

[38] See EFUS 2017 Heating and occupancy report
[39] See EFUS 2017 Heating and occupancy report, section 4.2
[40] Annex tables containing the underlying data for this section can be found in Tables_5_2.xls.

households reported that the living room was never uncomfortably cold and 52% that the main bedrooms were never uncomfortably cold.[41].

Figure 5.1: How often has the living room and main bedroom felt uncomfortably cold during winter



Base: All households (n=1,335 for living room, n=1,319 for bedroom (excludes bedsits)), Interview 2.

5.2.1 Living room thermal comfort by dwelling and socio-economic characteristics

This section explores the dwelling and socio-economic characteristics of those households who reported that their living room felt uncomfortably cold 'often' or 'always' (referred to going forwards as 'uncomfortably cold'). The main findings were:

- **Tenure**, where owner-occupiers were less likely (5%) to feel uncomfortably cold compared with households in the private rented (28%), housing association (21%) or local authority tenures (23%)
- **Age of the HRP**, where households where the HRP was aged between 16-34 years were more likely (27%) to feel uncomfortably cold compared with households where the HRP was 45 or older (4% to 11%)

[41] Thermal comfort information for bedsits was recorded as a living room rather than the main bedroom in EFUS (13 cases). The question assumes the householder responded about the main living room, if more than one was present.

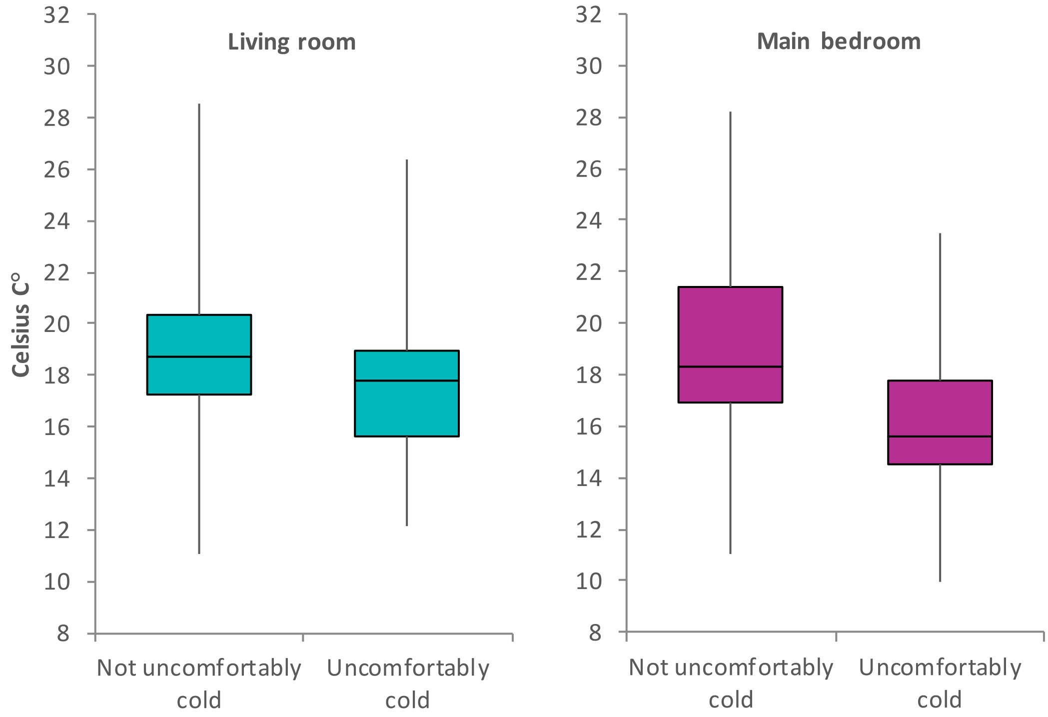
- **Household composition**, where lone parents with a dependent child(ren) (28%) were more likely to report frequently feeling uncomfortably cold in the living room than other types of households except other multi-person households (22%) and single households aged 60 years or less (17%)
- **Household income**, where households in the lowest quintile were significantly more likely (21%) to feel uncomfortably cold than other households (6% to 10%) except those in the 2nd income quintile (16%)
- **Dwelling age**, where households living in the oldest homes (pre-1919) were more likely (20%) to report being uncomfortably cold in winter compared with households living in dwellings built between 1965-1974 (8%) and those living in dwellings built post-1990 (7%)
- **Dwelling type**, where households living in detached houses were less likely to feel uncomfortably cold (4%) compared with households living in end or mid-terraced houses (18%) or flats (17%). This is somewhat surprising as intuitively it might be expected that households in detached houses might be more likely to feel uncomfortably cold because they have more external (heat loss) walls; it seems likely that this finding is more driven by the characteristics of the households living in these types of properties
- **Pensioner present**, where households without a pensioner present were significantly more likely (15%) to feel uncomfortably cold than households with a pensioner present (6%)
- **Floor area, wall type, levels of wall and loft insulation and the presence of double glazing** also had some impact on whether households felt uncomfortably cold in their living room. In general, dwellings with greater levels of insulation were less likely to feel uncomfortably cold in their living room, for example, households in homes without insulated walls (16%) were twice as likely to report feeling uncomfortably cold in their living room than those with wall insulation (8%).
- **Fuel poverty**, where fuel poor households were twice as likely (23%) to feel uncomfortably cold in their living room compared with households not in fuel poverty (11%). These findings are likely to be due to poorer households being unable to afford to heat their living rooms to a comfortable level.
- **Under-occupiers**, where households not under-occupying their home were significantly more likely (15%) to feel uncomfortably cold in their living room compared with those under-occupying (7%)
- **Children present**, where households with at least one child were more likely (17%) to feel uncomfortably cold in their living room compared with households with no children (10%).

Analysis by the key variables derived in the Heating patterns and Occupancy report showed:

- There was no relationship between the use of supplementary heating in the living room and reported winter thermal discomfort; 12% of households who used supplementary heating in their living room reported feeling uncomfortably cold, as did 12% of households who only used their main heating in their living room. Nor was there any significant difference in the banded hours of main heating between households that reported being uncomfortably cold and those who did not.

- There was a significant difference in the reported thermostat set point and reported winter thermal discomfort, where households reporting a thermostat set point temperature greater than 22°C were more likely to report feeling uncomfortably cold in the living room (23%) compared with households with a thermostat set point between 18 to 22°C (8%)
- In contrast, during the winter period the mean internal temperature in the living room was significantly lower at the 95% level for those households that reported feeling uncomfortably cold (mean 17.6°C) compared with households that did not (mean 18.8°C) (Figure 5.2)

Figure 5.2: Boxplot of mean winter 17/18 internal temperatures by households feeling uncomfortably cold, or not



Base: All households with measured temperatures, with Interview 2 responses (n=490 for living room, n=472 for bedroom (excludes bedsits)), Interview 2.

5.2.2 Bedroom thermal comfort by dwelling and socio-economic characteristics

Analysis of households who reported feeling uncomfortably cold in the bedroom, showed many similarities but also some differences compared with the results seen for the living room. Specifically, the similarities observed were:

- The nature of the differences between categories for tenure, pensioner present, and under-occupancy were the same as those observed for the living room

- The dwelling type and dwelling age differences were similar again for bedrooms, with differences observed between detached dwellings (3%) and flats (17%), and for dwelling age between pre-1919 (16%) and post-1990 (4%) properties. Differences for floor area were also similar
- Differences were broadly similar for household composition and age of HRP, where couples aged 60 or over were significantly less likely (5%) to feel uncomfortably cold in their bedroom compared with lone parents with dependent children (18%) and one person households aged under 60 (17%). Households where the age of the HRP was between 16 to 34 years were more likely (17%) to report feel uncomfortably cold in the bedroom compared with households where the HRP is aged 65 years or older (5%)

Factors related to the energy efficiency of the dwelling were found to be significant for the bedroom:

- EPC band Households living in the least energy efficient homes, EPC bands F to G were significantly more likely (31%) to feel uncomfortably cold in the bedroom than households living in homes with EPC A to C bands (8%)
- Main heating fuel Households using electricity were more likely (22%) to feel uncomfortably cold in the bedroom compared with households using gas or other fuels (8%)
- Dwelling type Households living in flats were more likely (17%) to feel uncomfortably cold than houses (8%)
- Main heating system Households living in homes without central heating were significantly more likely (22%) to feel uncomfortably cold in their bedroom compared with households with central heating (8%)

Analysis by the key variables derived in the Heating patterns and Occupancy report showed:

- In contrast to the results seen for living rooms, households with supplementary or alternative heating were more likely (29%) to be uncomfortably cold in their main bedroom compared with households using just the main heating system (8%)
- Similarly to the findings for living rooms, there were no significant difference in the banded hours of main heating between households that reported being uncomfortably cold in their main bedroom and those that did not, and households reporting a higher thermostat set point temperature were more likely to report feeling uncomfortably cold in the bedroom (16%) compared with households with a thermostat set point between 18 to 22°C (6%). As was seen in living rooms, during the winter period the mean internal temperature in the main bedroom was significantly lower for those households that reported feeling uncomfortably cold (mean 16.0°C) compared with households that did not (mean 18.4°C)(Figure 5.2)

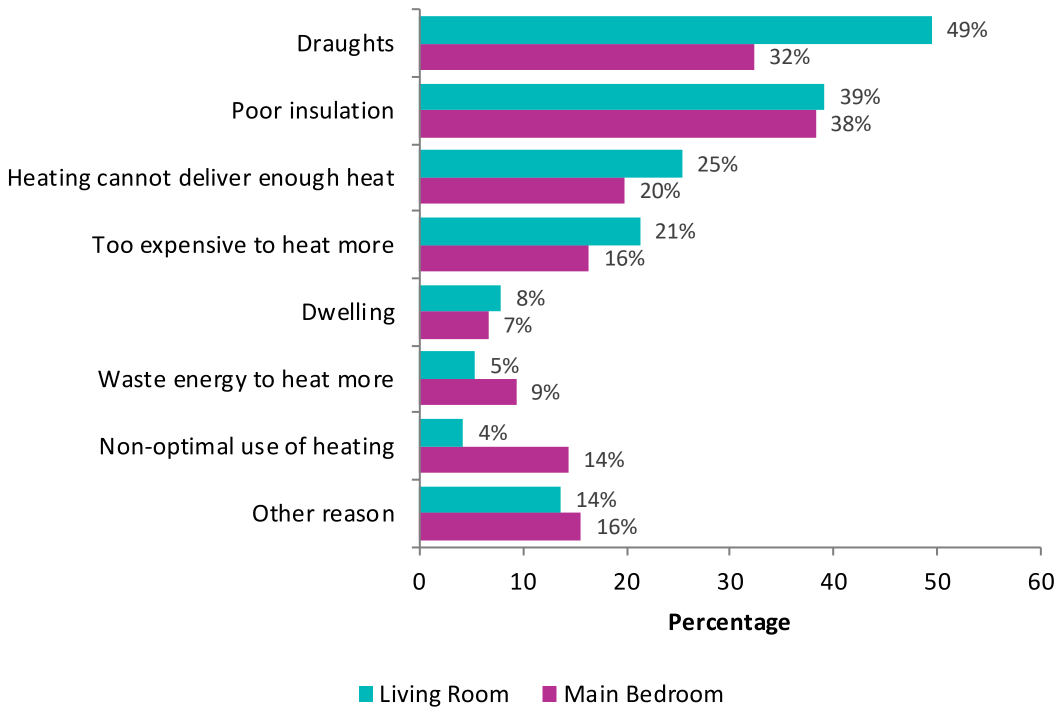
5.2.3 Multivariate analysis

A multivariate modelling approach that mirrored that undertaken for exploring self-reported summer overheating (section 4.2.4) was undertaken for the self-reported winter thermal discomfort. As found for the summer overheating multivariate analysis, no subset of the variables (households and dwelling characteristics) used in this analysis made a good model for predicting whether a household self-reported being uncomfortably cold in their living room, or main bedroom.

5.2.4 Reasons for the living room/main bedroom feeling uncomfortably cold

Of the households who reported feeling uncomfortably cold ‘often’ or ‘all the time’, the four most common responses to the question of ‘Why does the room get uncomfortably cold?’ were ‘draughts’, ‘poor insulation’, ‘heating cannot deliver enough heat’ and ‘too expensive to heat more’, for the living room with ‘poor insulation’ being more often reported than ‘draughts’ for main bedrooms (Figure 5.3). Of the 2.7 million households that reported feeling uncomfortably cold ‘often’ or ‘all the time’ in their living room and gave a reason, 49% (1.4 million) attributed it to draughts. For the 2.2 million who reported an uncomfortably cold main bedroom, 38% (851,000) attributed it to poor insulation.

Figure 5.3: Reasons reported by household feeling uncomfortably cold in their living room and main bedroom during winter

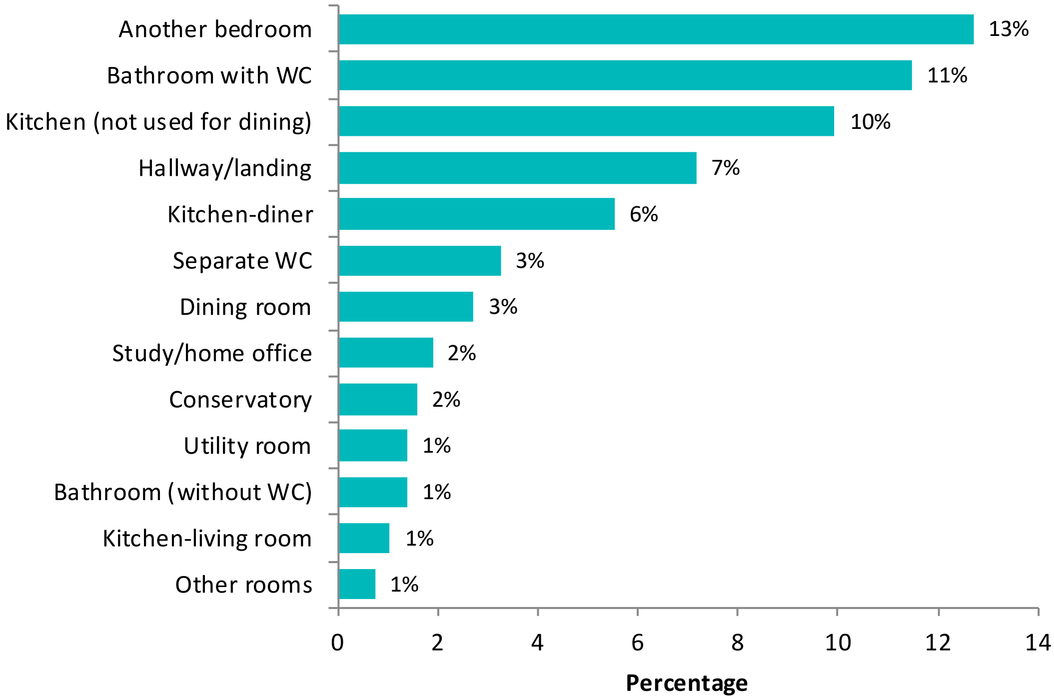


Base: All households who reported that their living room/main bedroom felt uncomfortably cold ‘often’ or ‘all the time’ in winter and gave a reason (n=164 living room, n=136 main bedroom (excludes bedsits)), Interview 2.

5.2.5 Other rooms

Householders were asked ‘Which, if any, of the other rooms in your house have generally felt uncomfortably cold this winter?’. Overall, 42% of all households reported that other rooms in their homes were uncomfortably cold. Around one-fifth of these households also felt uncomfortably cold in their living room or main bedroom. The rooms most commonly reported to be uncomfortably cold in winter were; another bedroom (13% of all households); bathroom with WC (11% of all households); kitchen (not used for dining) (10% of all households) and the hallway/landing (7% of all households) (Figure 5.4).

Figure 5.4: Other rooms reported to be uncomfortably cold during winter



Base: All households (n=1331), Interview 2.

Householders were also asked ‘In which (if any) rooms do you have problems with draughts?’. Over half of households (55%) said they did not have problems with draughts in any rooms. The rooms identified most often as draughty were a living room (24% of households) followed by a hallway/landing (15% of all households), a bedroom (14% of households), a kitchen (not used for dining) (8% of all households) and a bathroom with WC (5% of all households).

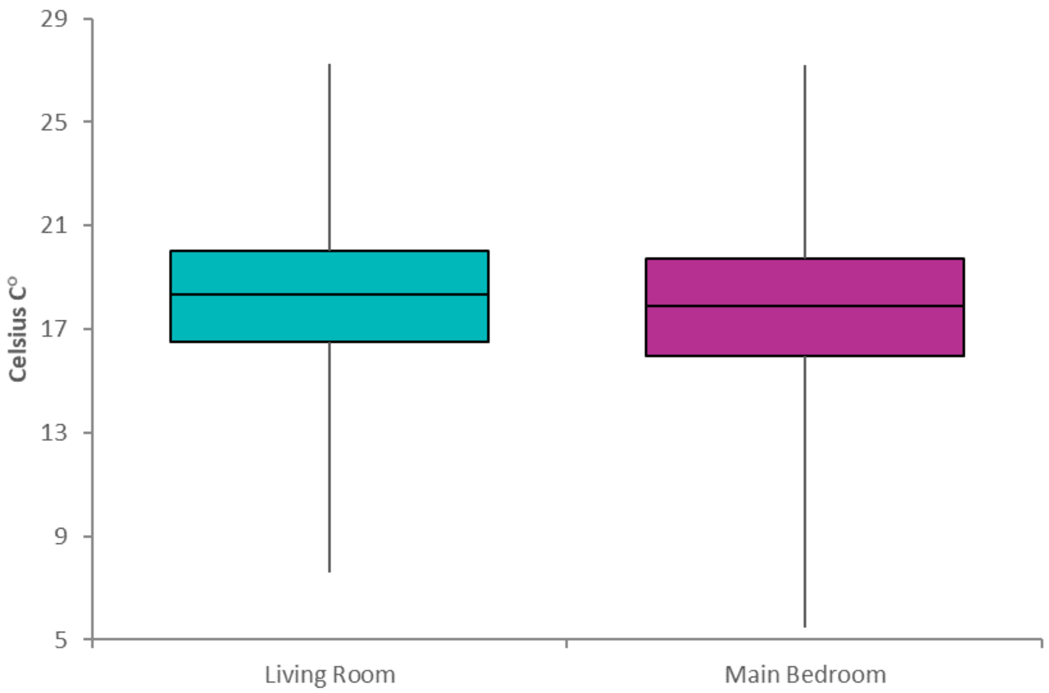
5.3 Thermal comfort during the coldest week

The coldest week in the winter of 2018/2019 occurred from Monday 28th January 2019 to Sunday 3rd February 2019[42],[43]. The average external temperature for this period, within the

[42] A week was selected in the 2018/19 winter season rather than during the 2017/18 winter, in order to overlap with the detailed gas consumption data investigated in the Energy Consumption and Affordability report.
[43] Annex tables containing the underlying data for this section can be found in Tables_5_3.xls.

EFUS sample, was 0.9°C. Despite the cold external temperatures, most households maintained a reasonably constant temperature throughout the week in their living rooms; 50% of households had a temperature greater than 18.3°C in the living room and 17.9°C in the main bedroom (Figure 5.5)[44]. These average temperatures were colder compared with the Winter 2018/19 average – by 0.8°C in the living room and 0.9°C in the main bedroom.

Figure 5.5: Average temperatures in living rooms and main bedrooms across the 'coldest week'

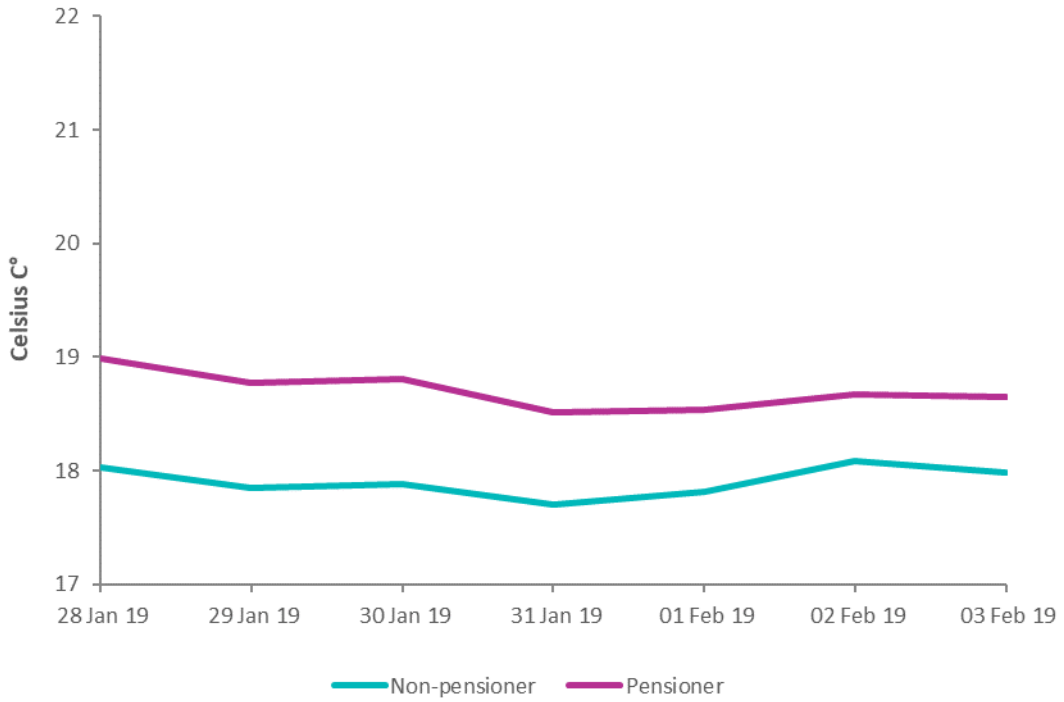


Base: All households with measured temperatures (n = 691, living room; n=672, main bedroom).

Differences in mean living room and main bedroom internal temperatures across the dwelling and socio-economic groups for this coldest week were similar to those seen for the overall winter period. A higher mean temperature for the week (in both rooms) was seen in the more efficient A to C EPC banded dwellings. Differences related to the age of occupants, daytime occupancy and under-occupancy were indicated for the living room at the 95% level, for example households with a pensioner present had a higher living room temperature (18.7°C) than those without (17.9°C) and households with someone in all day had a higher living room temperature (18.7°C) than those out all day (17.3°C). In the main bedroom, under-occupiers had a lower temperature (17.3°C) compared with those not under-occupying (18.3°C). The daily average living room temperatures, across the coldest week, for households with and without a pensioner present are shown in Figure 5.6.

[44] Gas consumption during the coldest week is discussed in the EFUS 2017 Energy Consumption report.

Figure 5.6: Daily average living room temperatures for pensioner and non-pensioner households during the coldest week



Base: All households with measured temperatures (n = 468). Note: Significance differences for all days at the 95% level except 2nd and 3rd of Feb.

There was some evidence that a small number of households struggled to heat their living rooms on the coldest days. A weekly average living room temperature below 16.1°C was evident for the coldest 20% of households (ranked by living room temperatures). Similarly, the coldest 20% of households (ranked by main bedroom temperatures) had a weekly averaged temperature in their main bedroom below 15.6°C It should be noted that this analysis was not able to account for householders not occupying their dwelling, for whatever reason, at that time.

It is of interest to note that, for living rooms, none of the categories within any socio-economic group were more prevalent in the coldest quintile; however for main bedrooms there was an indication at the 95% level that households with a pensioner present were more likely (24%) to be in the coldest 20% of households compared with households without a pensioner present (14%).

6. Winter ventilation behaviour

This section examines household behaviours in alleviating moisture in their home due to bathing/showers and indoor clothes drying.

6.1 Window opening and extractor fans in bathrooms

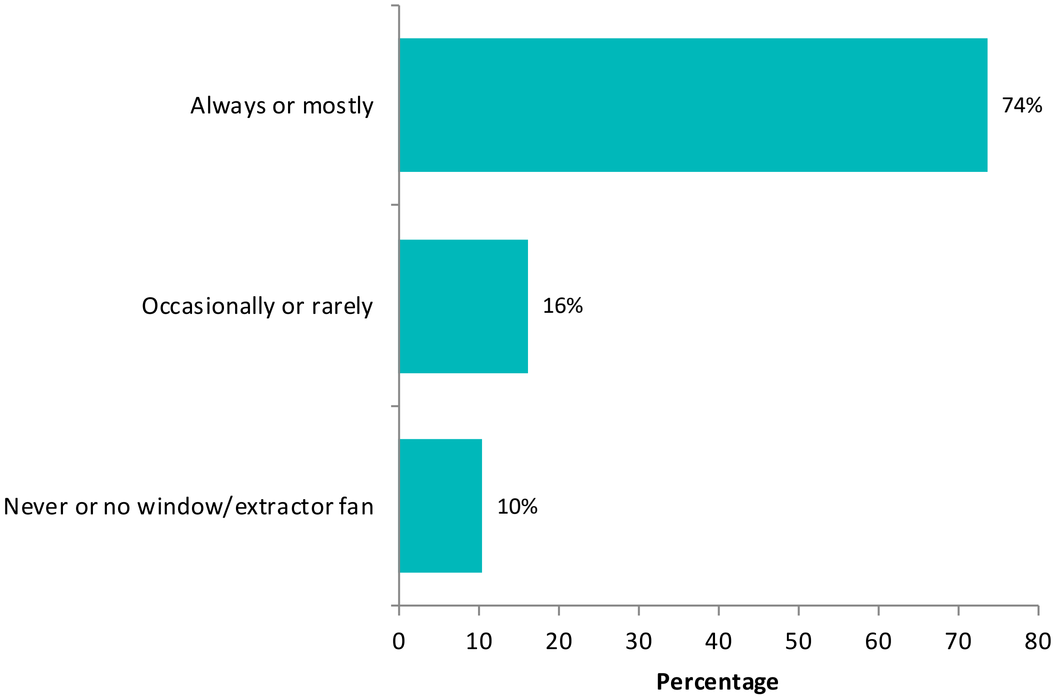
Households were asked ‘During the winter, how often do you OPEN THE WINDOW in your bathroom(s) during, or immediately after, you have had a bath or shower?’[45]. In total 12% of households reported that they did not have a window or it did not open, where, perhaps unsurprisingly, dwelling type was an underlying factor with 36% of flats reporting no openable window compared with 6% of houses. Of households with a window in the bathroom over a third (37%) reported that they always opened the window during/after a bath or shower, a further 13% reported ‘mostly’, while 22% reported to never open the window.

Households were also asked ‘If you have one, during the winter how often do you USE THE EXTRACTOR FAN in your bathroom(s) during, or immediately after, you have had a bath or shower?’. Over a third of households (38%) said they did not have an extractor fan or that it was not working, where more modern dwellings were more likely to have an extractor fan: post-1990 dwellings (92%) compared with older dwellings (49% to 65%); and energy efficient properties with an EPC rating of A to C (77%) compared with less energy efficient dwellings (40% to 59%). Among households with a working extractor fan (14.9 million), 71% reported that they always used the fan during/after a bath or shower, a further 5% reported ‘mostly’, while 12% reported never using the extractor fan[46].

Combining the responses for using a window or extractor fan in the bathroom, 74% reported to always or mostly ventilate their bathroom during/after using the bath or shower, and 16% occasionally or rarely (Figure 6.1).

[45] Annex tables containing the underlying data for this section can be found in Tables_6_1.xls.
[46] It should be noted that these figures include those for whom the fan starts automatically (coded as always), for example when the light or shower is turned on; information on the number of these was not obtained from the survey.

Figure 6.1: How often households use ventilation in their bathroom(s)(using a window or extractor fan) during or immediately after they have had a bath or shower



Base: All households (n=1338), Interview 2.

Almost half a million households (2%, 428,000 households), reported no means of ventilating their bathroom, and combined with households who reported never opening the window or using their extractor fan, resulted in 10% of households with no reported ventilation use in the bathroom. The following dwellings and households were more likely to not ventilate their bathroom:

Energy efficiency Households with lower energy efficiency ratings (F to G, 32%; A to E, 9%), and households with non-central heating systems and uninsulated walls

Household size Single person households (17%) compared with households with 3 or more people (3% or n<5), and households without children

6.2 Indoors clothes drying and ventilation

Households were asked 'During the winter, do you ever dry your clothes indoors, e.g. on radiators or a clothes rack?' (this explicitly excluded tumble drying)[47]. Overall, 83% (19.8 million) of households reported that they dried clothes indoors during the winter at least some of the time. This figure is notably high but, due to the question phrasing is likely to include

[47] Annex tables containing the underlying data for this section can be found in Tables_6_2.xls.

those who only occasionally dry some items of clothing, as well as those who use this method to dry all their clothes.

The households who reported drying their clothes indoors in winter were then asked; ‘When drying your clothes indoors during the winter, how often do you open a window, door, or turn on an extractor fan in the area where the clothes are drying?’. Of the households who dried their clothes indoors, less than one quarter (22%) either ‘always’ or ‘mostly’ opened a window or turned on an extractor fan in the area where the clothes were drying, with 47% of households reporting to never open a window or turn on an extractor fan. The following dwellings and households were more likely to report using ventilation ‘always’ or ‘mostly’ when drying clothes indoors: smaller dwellings (<50m2: 34%) compared with larger dwellings (90m2 or more: 12% to 14%); flats (30%) compared with houses (20%); social tenures (Local authority, 32%; Housing association, 35%) compared with owner occupiers (19%); and households not under-occupying (25%) compared with under-occupiers (15%).

6.3 Other reasons for regular window opening

Just under 6.3 million households (26%) reported opening windows and/or doors to air the house ‘every day’ during the winter, for example to let stale air and smells out and fresh air in[48]. A further 18% opened their windows ‘most days’, and the remaining 56% never, occasionally or rarely opened their windows.

To establish the main reasons why householders regularly open their windows during the winter respondents were asked whether they regularly opened their or windows or doors in the winter for any reason other than when showering/bathing or drying clothes. The most common reported reasons for regular opening of windows in the winter were; cooking (61%); letting pets in and out (30%); sleeping with windows open (28%) and letting the heat out if it gets too hot (22%).

[48] Annex tables containing the underlying data for this section can be found in Tables_6_3.xls.

7. Damp and mould

Condensation is the most common kind of damp in homes and is caused by moist warm air condensing on cool walls, particularly in rooms that generate a lot of air moisture, namely kitchens and bathrooms. Poor ventilation can impede the flow of air through the home preventing moisture from escaping or evaporating. Humid walls can also create a coldness that may increase the use of heating and add to energy bills. Mould growth may cause or exacerbate health problems such as respiratory infections or asthma. Condensation and mould are mainly, but not always, a problem households experience in the winter months, as external walls tend to be colder than the air inside.

7.1 Presence of damp and/or mould

Overall 27% of households reported the presence of some damp and/or mould patches on the walls or ceilings in their home[49]. Households with damp and/or mould patches most commonly reported these to be in the bedroom (53% of households with damp problems) or the bathroom with a WC (40% of households with damp problems). These proportions equate to 3.4 million and 2.6 million households respectively.

Analysis by socio-economic characteristics and dwelling characteristics showed that the following households were more likely to report damp and/or mould patches in at least one room:

- **Household composition lone parent households with dependent children** (48%) were most likely to report damp and/or mould problems, whilst single person households aged 60 or over were the least likely (13%) to report this problem
- **Households not under-occupying** were more likely (34%) to report damp and/or mould problems compared with households that were under-occupying (13%)
- **Age of HRP**, households where the HRP was aged 54 or under (ranging from 32% to 40%) were more likely to report damp and/or mould problems compared with households where the HRP was 65 or older (ranging from 14% to 16%)
- **Tenure**, households living in the private rented sector (41%), housing association (37%) or local authority housing (34%) were significantly more like to report damp and/or mould problems compared with owner occupiers (20%)
- **Number of persons in the household**, households with 5 or more persons (49%) were much more likely to report a problem than households of 2 people (25%) or 1 person (19%)

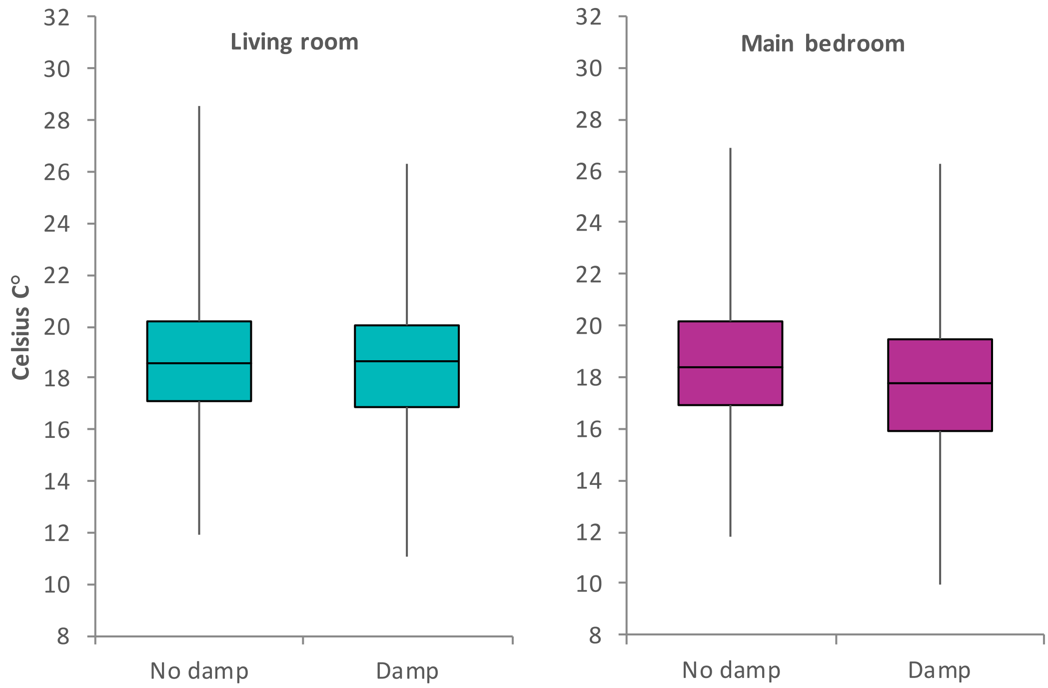
[49] Annex tables containing the underlying data for this section can be found in Tables_7_1.xls.

- **Income**, households in the lowest income quintile (41%) were more likely to report damp and/or mould problems compared with those in the highest two income quintiles (ranging from 16% to 23%)
- **Dwelling age**, households that lived in the oldest homes (pre 1919, 39% and 1919-1944, 32%) were more likely to report problems with damp and/or mould than households living in post 1990 dwellings (17%)
- **Pensioners**, households with no one over the state pension age were more likely (32%) to report this problem compared with households with someone over the state pension age (16%)
- **Children present**, households with dependent children were more likely (39%) to report damp and/or mould than households with no dependent children present (23%)
- **Dwelling type and floor area**, households living in mid-terraced houses (37%), flats (31%) and end-terraced houses (30%) were more likely to report damp and/or mould in their homes compared with those living in detached houses (15%); in conjunction with this there were significant differences seen for floor area, with households living in smaller dwellings being more likely to report damp and/or mould patches compared with larger dwellings although the results were not clear cut
- **Wall type**, households in dwellings with solid walls were more likely (35%) to report damp and/or mould problems compared with those with cavity walls (23%)
- **EPC**, households with an EPC E rating (36%) and F or G rating (40%) were more likely to report damp and/or mould problems compared with those in the A, B and C bands (21%)
- **Number of insulation measures**, households with no insulation measures (41%) were more likely to report damp and/or mould problems compared with those with 2 insulation measures (24%) or all 3 insulation measures (24%)
- **Fuel poor households**, were more likely to report problems with damp and/or mould (42%) compared with non-fuel poor households (25%)
- **Walls insulated**, households with no wall insulation (32%) were more likely to report damp and/or mould problems compared with those with insulated walls (23%)
- **Main heating system**, households with non-central heating (40%) were more likely to report damp and/or mould compared with household with central heating (26%)
- **Households with someone employed** (30%) were more likely to have damp and/or mould compared with household with no-one employed (22%)

With regard to some of the main heating behaviours, at the 95% level there is evidence to suggest that households heating their homes for fewer hours (up to 4 hours per day) were more likely to report a problem with damp and/or mould in their home (36%) compared with households heating their homes for more than 10 hours per day (20%).

There was no significant difference in the reported thermostat set point temperature between households with and without damp problems. There was also no significant difference in the measured mean winter living room internal temperatures in households with and without reported damp (mean of 18.4°C in households with a damp problem; mean of 18.7°C in households without a damp problem). However, there was a significant difference in the mean winter main bedroom internal temperatures, with colder bedroom temperatures measured in households with damp (mean, 17.5°C) compared with households with no damp problems reported (mean 18.5°C) (Figure 7.1)

Figure 7.1: Living room and main bedroom internal temperatures in homes with, and without, reported problems with damp.



Base: All households with measured temperatures (n=488 for living room, 474 for main bedroom)

7.1.1 Multivariate analysis

A multivariate modelling approach that mirrored that undertaken for exploring self-reported summer and winter thermal discomfort was undertaken for households reporting damp and/or mould growth. None of the models created provided a good fit for predicting reported problems with damp and/or mould growth and were unable to provide any additional insight to that found by bivariate analysis; the ‘best’ model contained the age of the dwelling, floor area, whether the dwelling had central heating, tenure, household composition and the number of dependent children.

7.2 Influence of household ventilation behaviours

There was no significant difference between households that reported damp and/or mould in (any room) in their homes and those that did not, when explored by the following behaviours, that might be thought to increase the likelihood of damp and or mould[50]:

- **Airing the house** There was no significant difference in the likelihood of reporting damp and/or mould in the home and how often the windows/doors were opened to air the house in the winter; 25% of households who aired the house every day or most days reported damp and/or mould compared with 29% of households who aired the house occasionally, rarely or never
- **Bathroom ventilation** There was no significant difference in the likelihood of reporting damp and/or mould in the home and how often ventilation is used in the bathroom; 27% of households who used a window or extractor fan in the bathroom reported damp and/or mould compared with 28% of households who never used a window or extractor fan (or no window/extractor fan was present)
- **Drying clothes indoors** There was no significant difference in the likelihood of reporting damp and/or mould in the home and the drying of clothes indoors during winter where 29% of households who always or mostly dried clothes indoors reported damp and/or mould compared with 28% of households who dried clothes indoors occasionally, rarely or never

Exploring the ventilation practices in the specific room/s in which householders reported damp and or mould problems, showed that of the 2.6 million households that reported damp and/or mould problems in a bathroom with a WC, around 60% reported opening a window or using an extractor fan every day, while 13% of households never used ventilation (or no window/extractor fan was present). For households that reported damp and/or mould in the bedroom (3.3 million households), around one third (35%) opened their window daily in winter while 19% never opened the bedroom window (or no window/extractor fan was present).

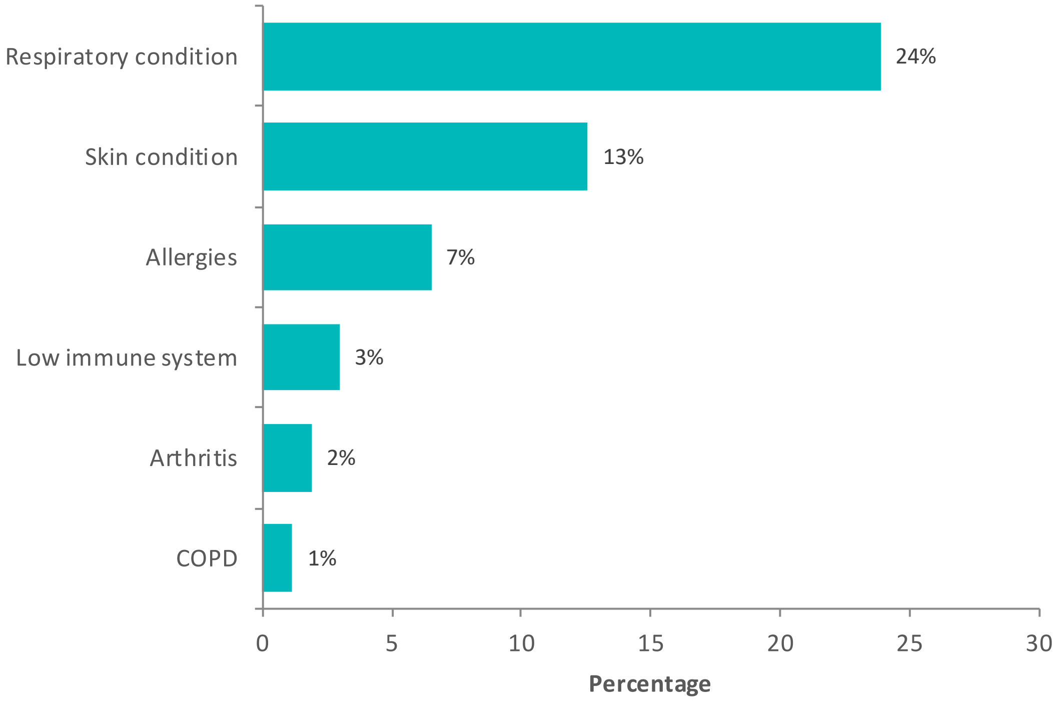
7.3 Damp, mould and health

Households who reported problems with damp and/or mould in their home were asked if any members of the household suffered from any medical conditions that were made worse by damp and/or mould[51].

Of the 6.5 million households who reported the presence of damp and/or mould, 36% (2.3 million households) reported that they had a medical condition made worse by damp; the majority of these reported that it was a respiratory condition (Figure 7.2), while 6% reported they did not know if they had a condition made worse by damp and 58% reported no condition made worse.

[50] Annex tables containing the underlying data for this section can be found in Tables_7_2.xls.
[51] Annex tables containing the underlying data for this section can be found in Tables_7_3.xls.

Figure 7.2: Conditions made worse by damp and mould



Base: All households reporting dampness and mould (n=370), Interview 2.

8. Conclusions

This thermal comfort, ventilation, damp and mould report is part of a series of reports that present the findings from the EFUS 2017. The Interview 1 survey and temperature logger data have provided information on the prevalence of summer overheating in homes. Information on the prevalence of winter thermal discomfort, how households ventilate their homes to mitigate the effects of warm weather and how households mitigate damp and mould problems arising/being exacerbated at their home was collected from the Interview 2 survey.

Overall, the years 2017 to 2019 covered by the EFUS 2017 were relatively hot years in comparison with the 30-year average (1981 to 2010) used by the Met Office. Winter 2017/18 included the cold period at the end of February 2018 dubbed the ‘Beast from the East’ by the media but mean temperatures for November and December 2018 were only 0.5°C higher than the 30-year average. This was followed by the warmest summer on record for England in 2018, and then a warmer than average Winter 2018/19 period. Internal temperatures were monitored in 750 households from October 2017 to April 2019 as part of the EFUS survey.

The main conclusions can be summarised as:

Summer thermal comfort

The dataset of summertime temperatures, measured in up to five rooms in 750 homes, is the largest ever collected in England. The data was gathered during England’s hottest ever summer (summer 2018), thus enabling the frequency of overheating in homes of different type and in different geographical areas to be studied along with the measures people take to combat heat. Whilst these results cannot therefore readily be interpreted in the context of a typical 2010s UK summer, they have provided potential insight into the effects of temperatures which may become typical of those that will be experienced in the 2050s.

The prevalence of summer overheating in the English housing stock has been made using two methods; an assessment using measured internal temperatures during 2018 and self-reported questions on thermal comfort collected from householders in 2017. Despite using two very different approaches to assessing overheating, physical measurement and self-reporting, the overall patterns of overheating as dwelling and household characteristics changed, as well as the statistical significance of these differences, were very similar. This strongly suggests that the inherent features of the English housing stock that lead to overheating have been clearly identified by this study.

The measured overheating results present findings based on contemporary UK adaptive criteria, which are increasingly seen as the more credible approach to assessing overheating in living spaces based on measurement. Different thresholds, above which people start to feel ‘thermally uncomfortable’, have been established through field measurement and are set, dependent on the vulnerability of occupants. These thresholds increase with the mean daily external temperature. Criteria, defining the frequency and degree of exceedance of these thresholds, determine what constitutes overheating.

The determination of whether households contain persons that are sensitive to heat, i.e. are vulnerable (TM52) or sensitive and fragile (BSEN15251) is important to the correct analysis of overheating prevalence. When this distinction was made, the number of living rooms deemed to overheat more than doubled, compared with the numbers obtained assuming all homes contain non-vulnerable individuals (15% compared with 7%). Most previous overheating studies have not accounted for occupant vulnerability in this way.

The use of the adaptive thermal comfort approach for assessing bedroom overheating is new. The approach was driven primarily by the implausibly high estimates of overheating (69%) obtained by the static (CIBSE) overheating criterion which uses a fixed 26oC threshold temperature; the adaptive approach gave results much closer to the self-reported incidence of overheating.

Using the adaptive thermal comfort approach, with the category of occupant determined by their heat-sensitivity, 15% of living rooms and 19% of main bedrooms were deemed to have overheated i.e. more than 3% of the occupied hours were over the temperature threshold. There were 22% of homes in which the main bedroom overheated for three or more consecutive nights during the summer.

The fact that bedrooms (except in flats) tended to overheat more than living rooms, and that there was no significant difference in the incidence of night-time overheating with dwelling type, is interesting. It is hypothesised that this is because bedrooms tend to be located on upper floors, and so are more exposed to solar gains and less protected by shading from trees, buildings and other objects. They are also more susceptible to the accumulation of warmed air from lower floors, perhaps situated below a warm attic (or heated flat above), and more likely to have a thermally lightweight floor. The results suggest that overheating mitigation measures could usefully focus on bedrooms, irrespective of dwelling type in which they are found.

The principal significant differences in the incidence of reported overheating related to the age of the HRP and factors associated with this, such as household composition and under-occupancy of home. Age may also explain the lower incidence of reported overheating in owner-occupied homes. However, extreme care has to be exercised in taking these results to mean that older households are actually less likely to be exposed to overheating. It may simply be that they do not perceive elevated temperatures as ‘uncomfortably warm’ even though they may be high enough to bring about health and well-being problems.

Overheating in living rooms and bedrooms was most often experienced by households who are amongst society’s most disadvantaged and vulnerable. There were some strong similarities in the self-reported and measured patterns of overheating within certain dwelling and socio-economic characteristics. For living rooms, both measured and reported overheating was higher in flats compared with houses, smaller dwellings compared with larger ones, households with low incomes compared with those on higher incomes and households in the social sector compared with those in private tenures. In main bedrooms, both the self-reported and measured results showed a greater prevalence of overheating in households with greater number of occupants and with children present.

There was also indicative evidence (both measured and self-reported) that a higher prevalence of overheating in living rooms was to be found in households living in dwellings in the London region. The regional finding is probably due to the higher ambient temperatures combined with urban heat island effects, and that a higher proportion of London dwellings are flats. The built-up nature of London may also curtail the opening of windows for cooling for security reasons, or because of noise and pollution. Whilst the finding related to EPC bands suggests that improved energy efficiency of dwellings may cause elevated indoor summertime temperatures, this is likely to be because there are significantly more flats in homes with a better EPC rating.

While differences in reported overheating were evident using bivariate analysis, logistic regression models suggest that any subset of household and dwelling characteristics do not perform well in predicting the likelihood of reported overheating by households.

Winter thermal comfort

The EFUS Interview 2 survey was delivered in February to March 2018 during the coldest period of the year and included questions examining the householders' perceptions of thermal comfort over the winter period in their living room and main bedroom. Over a third (34%) of all households never felt uncomfortably cold in their living rooms during the winter and over half (52%) never felt uncomfortably cold in their main bedroom. However, 12% said they 'often' or 'always' felt uncomfortably cold in the living room and 9% reported the same for the main bedroom.

Measured living room and main bedroom temperatures were lower in those households that reported feeling uncomfortably cold (living room: 17.6°C compared with 18.8°C; main bedroom 16.0°C compared with 18.4°C).

Although older occupants are most at risk, physiologically, of excess cold, the results of the EFUS 2017 show that, for living rooms, households in rented tenures (both social (21% to 23%) and private renters (28%)) were more likely to feel cold compared with owner occupiers (5%), as were the youngest households (HRP aged 16-34 year (27%)) compared with those aged 45 years and over (4% to 11%). Lone parents with dependent children, households on the lowest incomes and the fuel poor (23% compared with 11% in households not in fuel poverty) were all more likely to report being uncomfortably cold than their counterpart groups. These findings are likely to be due to poorer households being unable to afford to heat their living rooms to a comfortable level.

Households living in detached houses were less likely to report regularly feeling uncomfortably cold (in either the living room or main bedroom) than households in terraced houses or flats. This is a surprising finding given that flats and terraced houses typically take less energy to heat as they have fewer external walls and heat can be transferred from adjoining dwellings.

Consequently, this finding is more likely to be driven by characteristics of those living in these types of properties rather than characteristics of the dwellings themselves.

A dwelling's energy efficiency rating band was a significant factor in perceived levels of discomfort in the bedroom, where households living in the least energy efficient homes, EPC bands F to G were significantly more likely (30%) to feel uncomfortably cold in the bedroom than households living in homes with EPC A to C bands (8%). This may have been partly due to the type of main heating system, as households living in homes without central heating were significantly more likely (21%) to feel uncomfortably cold in their bedroom compared with households with central heating (8%).

The findings above link well with the variation across dwelling and socio-economic characteristics in measured mean living room and main bedroom temperatures. Dwelling age, energy efficiency rating and number of insulation measures had the largest impact on the mean internal temperatures in the living room and main bedroom; the oldest (pre-1919) dwellings were significantly colder (living room 17.7°C) than newer dwellings (post-1990 dwellings mean living room 19.1°C) and the most energy inefficient (EPC rated F or G) dwellings had significantly colder living room (17.2°C) and main bedroom (15.7°C) temperatures compared with A to C and D rated dwellings (living room 18.6°C to 19.3°C; bedroom 17.8°C to 18.9°C). Dwellings in rural locations and those with non-central heating systems also had significantly colder bedrooms compared with those in urban and centrally heated dwellings, respectively. Households with a pensioner present had higher mean living room temperatures (compared with younger households), as did households in the lower income groups. This is probably related to these households being more likely to be at home during the day.

Although there were no significant differences in the average hours of main heating between households that reported being uncomfortably cold in either the living room or the main bedroom and those who did not, households that reported feeling uncomfortably cold in these rooms generally reported setting their thermostat to a higher temperature. As the measured mean internal temperatures in the living room and main bedroom for the winter 2017/18 were significantly lower in households that reported being uncomfortably cold compared with households who were not this may be indicative of the inability of their heating system to provide the required level of warmth.

Logistic regression models indicated that no subset of household and dwelling characteristics performed well at predicting the likelihood of reported winter thermal discomfort among households. Consequently, these models were unable to provide more detailed information for the targeting of measures to assist specific households who are unable to attain desired internal temperatures during the winter.

The most frequently reported reason for why respondents' homes felt uncomfortably cold was draughts (reported by 49% of households that gave a reason for feeling cold), whereas for those feeling cold in their main bedroom it was poor insulation (reported by 38% of households that gave a reason for feeling cold). Overall 42% of all households reported that other rooms in their homes were uncomfortably cold, most commonly another bedroom (13%); bathroom with WC (12%); kitchen (not used for dining) (10%) and the hallway/landing (7%).

The coldest week was a week at the end of January/early February 2019, where external temperatures dropped to 0.9°C. Average living room temperatures were, on average, just under 1°C colder, both in living rooms and main bedrooms, compared with the Winter 2018/19 averages. The coldest 20% of households experienced a living room temperature below 16.1°C and the coldest 20% of households had a main bedroom temp below 15.6°C. Overall, 50% of households had a temperature greater than 18.3°C in the living room and 17.9°C in the main bedroom

Winter ventilation behaviours

The report examined the household behaviours in alleviating moisture in their home due to bathing/showers and indoor clothes drying.

Responses to window opening and extractor fan use were combined to give a better indication of the ventilation practices. Just 2% of households reported no means of ventilating their bathroom. For the remaining households, 74% reported always or mostly using either the window or an extractor fan to ventilate the bathroom. There were no significant differences in the socio-economic characteristics of households and the likelihood of them using or not using ventilation in the bathroom.

A notably high proportion (83%) of households advised that they dried clothes indoors during the winter at least some of the time and just under half (47%) reported never ventilating the room whilst doing do.

Overall, 26% of households reported that they open windows and/or doors to air the house ‘every day’ during the winter. Over half of all households (56%) reported that they never opened their windows.

Damp and mould

Overall, 27% reported the presence of damp and/or mould patches on at least some of the walls or ceilings in their home, most commonly in a bedroom or a bathroom. Among households who reported the presence of damp and/or mould, 36% reported that they had a medical condition made worse by damp; the majority of these reported that it was a respiratory condition. Self-reported presence of damp by households is not comparable to the far lower reported prevalence of damp (4%) and serious condensation and mould (2%) reported by surveyors as part of the English Housing Survey[52]; the surveyor observations of damp are

[52]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/817408/EHS_2017_Stock_Condition_Report.pdf

used in their assessment of the risk to health from damp as part of their Housing, Health and Safety Rating (HHSRS) assessments.

Many socio-economic characteristics of the household, and dwelling characteristics of the home showed significant differences in the likelihood of a household reporting a problem with damp and mould. Several socio-economic factors were statistically more important than the dwelling characteristics, suggesting that problems with damp were more to do with ‘who and how’ people use/occupy their homes than the actual dwellings themselves.

Household composition and size, tenure, income quintile and dwelling age and insulation characteristics were key factors affecting the prevalence of reported damp problems; a notably high proportion of the fuel poor (42%), lone parents with dependent children (48%) and households in the lowest income quintile (41%) reported issues with damp compared with their counterparts, as did those living in the oldest homes (pre-1919; 39%) and in the least energy efficient dwellings (EPC F or G band; 40%). The increased prevalence of reported problems with damp by households in fuel poverty could be due to a combination of factors including the types of dwelling they are living in and inadequate levels of heating for affordability reasons.

There was no difference in the winter mean living room temperatures measured in homes with a reported damp problem, but main bedrooms were colder in homes with damp compared with those without damp. There was no apparent influence of householders’ behaviours in terms of airing the house, ventilating the bathroom or drying clothes indoors on the prevalence of damp problems.

The findings suggest that there are many factors, other than just regularly opening the bathroom window, turning on the extractor and/or drying clothes indoors which affect the likelihood of experiencing damp and mould. The findings should not be interpreted as indicating that ventilating or extracting moist air out of the home does not have a significant effect on damp and mould levels. It is likely that there is a more complicated picture and other variables also influence the likelihood of experiencing damp and mould problems.

Glossary

Term	Description
Age of dwelling:	This is the date of construction of the oldest part of the dwelling. Recorded by surveyors in the EHS physical survey.
Age of HRP:	The Household Reference Person (HRP) is the person in whose name the dwelling is owned or rented or who is otherwise responsible for the accommodation. In the case of joint owners and tenants, the person with the highest income is taken as the HRP. Where incomes are equal, the older is taken as the HRP. This procedure increases the likelihood that the HRP better characterises the household's social and economic position. The age of the HRP is derived from; variables obtained from the EHS Interview survey for households that had not changed since the earlier EHS interview. householder responses to questions 45-50 in EFUS Interview 1 and questions 41-45 in EFUS Interview 3 for new households
Alternative heating:	Heating system present in a room (or rooms) used as an alternative to the main heating system.
After housing costs equivalised income – weighted quintiles:	This is calculated based on the fuel poverty income (from 2015 & 2016 fuel poverty datasets) and updated to account for any changes to income at Interview 1 and Interview 3 EFUS questionnaires. Validation of income based on reasons why household income had changed for the Interview 3 questionnaire provided increased confidence and reliability of the income.
Boiler type:	Derived from the EHS data.
Children Present:	Anyone in the household who is 16 years old or younger at the time of the EFUS interview. This is derived from; variables obtained from the EHS Interview survey for households that had not changed since the earlier EHS interview. householder responses to questions 45-50 in Interview 1 and questions 41-45 in Interview 3 in the EFUS questionnaires for new households
Daytime Occupancy	Derived from the EFUS survey. A household has been classified as being 'in during a weekday' if they indicated being generally in the house on weekdays during the winter, for both the morning and afternoon periods. A household is classified as 'not in during the day' if they responded as not being in for both the

Term	Description
	morning and the afternoon periods. Households who were in for either the morning or afternoon period were coded as 'Variable' occupancy.
Dwelling insulation:	The number of insulation measures (0 to 3) where positive responses for 'fully double glazed', 'insulated walls' and having loft insulation greater than 200mm count as insulation measures. EFUS Interview 1 and interview 3 questionnaires asked respondents about new insulation measures installed since the EHS survey. New windows installed since the EHS survey are excluded from the analysis as it cannot be assumed that this resulted in the dwelling being fully double glazed.
Dwelling type:	Classification of dwelling on the basis of the surveyors' inspections during the EHS physical survey.
Employment status of the household:	Derived from W1_q56 of EFUS Interview 1, and the modelling assumes responses are for all adults in the household (HRP, partner and any other additional adults in employment). 'Don't know' responses were coded as having no employment. Households either have at least one person employed, or all adults are unemployed.
Energy Performance Certificate (EPC) band:	Energy Performance Certificate band, also sometimes known as the Energy efficiency rating (EER) band (SAP 2012) of the dwelling. Bands from A to G that are used in the Energy Performance Certificate. 'A' is the most efficient and 'G' is the least efficient. Derived from the SAP 2012 methodology used for the 2016 EHS. SAP2012 was re-modelled for dwellings which have had improvements between the EHS and EFUS Interviews 1 and 3.
Fuel poverty status:	A household is considered to be fuel poor if: they have required fuel costs that are above average (the national median level); were they to spend that amount, they would be left with a residual income below the official poverty line. Each household's fuel poverty status has been updated using EFUS data on household changes, incomes and modelled fuel costs due to dwelling improvements
Fuel poverty gap:	The difference in pounds between the required energy costs for each fuel poor household and the nearest fuel poverty threshold.
Fuel type of main heating system:	As recorded by surveyors in the EHS physical survey. Grouped into 'mains gas', 'electricity' and 'other', which includes bottled gas, bulk gas, solid fuels, oil and community schemes. The data was updated at Interview 2 and Interview 3 if a household reported using a different main heating system.

Term	Description
	Assumptions for households reporting having central heating but did not answer about fuel type: - Set to mains gas if a mains gas connection was recorded in the EHS - If not on mains gas set to EHS recorded main fuel - If reported not on gas in EFUS Interview 1, then categorised as 'other' gas (e.g. bottled).
Fully double glazed:	Derived from the 'dblglaz4' EHS variable as recorded by surveyors in the physical survey. Fully double glazed is defined as 'entire house double glazed'. Not fully double glazed is anything less than fully double glazed. New windows installed since the EHS survey were excluded from the analysis as it could not be assumed that this resulted in the dwelling being fully doubled glazed.
Heating season:	The months when there is a requirement for the main heating system to provide heat. For the EFUS 2017 survey this is calculated based on householder responses to a question in Interview 2 (what month heating began every day) and a question in Interview 3 (what month heating stopped every day), both asked in relation to Winter 2017/18.
Household size:	Number of persons in the household, banded into 5 groups, derived from the 'hhsizex' variable from the EHS Interview survey. The data was updated following any changes to household composition recorded in EFUS Interview 1 and Interview 3 questionnaires.
Insulated walls:	Derived from the 'wallinsx' variable as measured by surveyors in the EHS physical survey and refers to any insulation for the predominant wall type. The 'solid uninsulated' category includes non-cavity other wall types such as timber, steel or concrete framed. EFUS Interview 1 and Interview 3 questionnaires asked the household about the installation of wall insulation since the EHS survey and the 'wallinsx' variable was updated.
Loft insulation:	Banded variable of 'loftinsx', the level of loft insulation recorded by surveyors in the EHS physical survey. EFUS Interview 1 and Interview 3 questionnaires asked the household about the installation of loft insulation since the EHS survey and the 'loftinsx' variable was updated
Long-term sickness or disability:	Whether anyone in household has long-term illness or disability that limits their activities. And/or whether anyone in the household is registered disabled. This is self-reported by EHS interview respondents.

Term	Description
Pensioner Present:	Anyone in the household who is of state pension using data from the EHS Interview survey. Updates using responses to questions 45-50 in Interview 1 and questions 41-47 of Interview 3 EFUS questionnaires.
Region:	Government Office Region that the dwelling is located in. Obtained from the EHS.
Rurality:	Is the dwelling in a rural (village or isolated hamlet) or urban (urban or town or fringe) location. Derived from the 'rumorph' variable in the EHS.
SAP rating:	The energy cost rating as determined by Government's Standard Assessment Procedure (SAP) and is used to monitor the energy efficiency of dwellings. It is an index based on calculated annual space and water heating costs for a standard heating regime and is expressed on a scale of 1 (highly inefficient) to 100 (highly efficient with 100 representing zero energy cost). An updated SAP rating was modelled for dwellings which had improvements between EHS and EFUS Interviews 1 and 3.
Supplementary heating:	Heating systems used in addition to the main heating system to boost internal temperatures.
Tenure:	Derived from the EHS but updated from householder responses in EFUS to q52 in Interview 1 and Q51 of the Interview 3. Cases responding 'don't know' left as the original EHS category. The modelling assumes a response of 'renting' to be a household living in the private rented sector.
Type of (main) heating system:	Derived from the EHS but adjusted for EFUS Interview 2 and Interview 3 responses (question 02). Grouped into central heating or non-central heating categories. Non-central heating includes storage radiators, gas fires, electric heaters, coal/wood/ smokeless fuel fires or stoves and other less common systems.
Under-occupying:	A household is considered to be under-occupying if the dwelling is more than large enough for the number (and type) of occupants living there. For the full definition of under occupancy, see the fuel poverty methodology handbook, which is available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/829010/Fuel_Poverty_Methodology_Handbook_2019.pdf
	Derived from EHS data and updated based on age and household changes at EFUS Interview 1 and 3.

Term	Description
Useable floor area:	The total usable internal floor area of the dwelling as modelled for the EHS 'floorx', rounded to the nearest square metre. It excludes integral garages, balconies, stores accessed from the outside only and the area under partition walls. Grouped into 6 categories.
Water heating system	Derived from EHS data. Categories are: 'with central heating', 'dedicated boiler', 'electric immersion heater', 'instantaneous', 'other'.

Appendix A: Assessing overheating from measured temperatures

Analysis assumptions: To assess the measurements against the overheating criterion the following assumptions and conventions were adopted:

- The measured temperatures, as recorded by the Tinytag loggers, were used in place of true operative temperature (TO)
- Half hourly temperatures were rounded, as suggested in TM52 (see footnote 16)[53]; these were then compared to the threshold values (Tmax) and the number exceeding the threshold divided by two to get the hourly threshold exceedance
- The daily running mean (Trm) outdoor temperature for the period from May to September for each dwelling was obtained from the nearest matched MIDAS station[54]
- When applying the adaptive criterion, the occupied hours for the living rooms was presumed to be 07:00 to 22:00 inclusive and for the bedrooms from 22:00 to 07:00 inclusive. In practice the rooms may not be occupied during some of these hours. The assumed occupancy periods align with those that have been adopted previously by overheating researchers. The living room is thus occupied for 15 hours a day, so 3% of occupied hours between May and September (153 days) is 69 hours. The bedroom is occupied for 9 hours a day giving a 3% threshold of 41.5 hours for the May to September period

All timings are based on British Summer Time (Greenwich Meantime plus one hour). See the EFUS Methodology report for further information.

[53] Without rounding, the headline prevalence of overheating in living rooms and bedrooms, as measured by the adaptive criterion (Cat.I or Cat.II depending on household vulnerability), substantially increased, from 22.2% of bedrooms with rounding to 31.5% with no rounding, and from 17.7% of living rooms to 25.0%.

[54] Homes where there were insurmountable difficulties with the MIDAS data were excluded from further analysis (for more details see the EFUS Methodology report).

Appendix B: Future work

Primary insight has been provided in this report, but further topics for investigative analysis could be considered to explore thermal comfort, damp and ventilation using the EFUS data. This could include:

- Investigate the extent to which households report both summer and winter thermal discomfort
- Exploring the reasons for overheating/underheating by how often the householder feels uncomfortably warm/cold
- Exploratory analysis of the links between thermostat settings and achieved internal temperatures
- Further work using the EFUS 2017 monitored temperatures, to assess how an assumed occupancy period would change results if at all.
- More depth analysis to determine how the usage of secondary heating changes during cold spells.

For dampness and mould, further exploratory work into the frequency of use of the bathroom/s, the density of occupancy, heating patterns and the physical attributes of the dwelling. It is noted that the EHS 2016 reported that 3.7% of dwellings recorded the presence of damp in at least one of the rooms surveyed, compared to 27% reported by households in this EFUS study. This discrepancy between measured and reported damp problems may be worth investigating further.

In addition, future research in this area could include;

- Exploration of any links between self-reported and/or measured overheating and construction types
- Further research into overheating and its link to ambient temperature. Likewise, the frequency, duration and severity of overheating in individual homes could be more thoroughly explored. The potential for more targeted public health advice, and the reliability of current advice, notably about seeking a cool room in which to sleep, could be also studied
- Finally, considerable background work, and numerous subsidiary explorations, were needed to settle on the method of analysis presented and applied in the analysis of measured overheating. This underpinning work could usefully be published in the open literature to guide other researchers and those undertaking future EFUS studies. Such work would thus build on a more solid foundation and ultimately lead to guidelines about how to determine the risk of overheating using physical measurement.

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