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Too hot, too cold? An analysis of factors associated with thermal comfort in English homes

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This paper focuses on factors associated with feeling too hot / too cold in English homes and compares internal temperatures for homes where occupants report either and those where not.
The data analysed for this paper are part of the Energy Follow-Up Survey (EFUS), commissioned by the Department of Energy and Climate Change (2013).
Across the sample (N = 2616), 6.7% of households reported that during cold winter weather, they cannot keep comfortably warm in the living room. 9.2% reported that during summer, they have difficulties to keep the living room and 11.3% to keep the bedroom cool.
In winter occupants in homes with uninsulated cavity walls and with less double glazing are more likely to indicate that they cannot keep comfortably warm. In summer, households with presence of a sick / disabled person were more likely to report that they cannot keep living rooms cool. Energy consumption and internal temperatures did not differ between those reporting discomfort and those who did not.
One important finding is the high degree of variability in internal temperatures. This variation of temperatures that householders apparently experience as comfortable is reassuring in that acceptable temperatures are not limited to a narrow range.

Keywords: thermal discomfort, internal temperatures, energy consumption, logistic regression, homes

1 Introduction

This paper focuses on factors and temperatures related to feeling too hot or too cold in one’s home. Data were collected from a sample of homes in England. Thermal comfort is often looked at a momentarily state linked to certain environmental parameters and personal factors. For example, in the heat-balance models the following six factors predict the occupants’ overall satisfaction with the thermal environment as expressed by the Predicted Mean Vote (PMV): (1) ambient air temperature (Ta), (2) mean radiant temperature (Tr), (3) relative humidity (RH), (4) air velocity (Va), (5) metabolic rate (met), and (6) clothing level (clo) (EN ISO 7730:2005, Annex D; Fanger, 1970). In adaptive models of thermal comfort additional factors are of importance, such as previous and current climatic experiences (Nicol et al, 1973). Also, a range of other factors have been discussed as impacting on thermal comfort such as gender (e.g. Karjalainen, 2012; Schellen et al, 2013), age (e.g. Olgyay, 1963; Schellen et al, 2010), and in general, weight and height are related to physiological parameters that in turn impact on thermal comfort (for an overview, see Huizenga et al, 2001).

This paper is not focused on momentarily determinants of thermal comfort, but rather looks at factors that are associated with feeling thermally uncomfortable in one’s home, and analyses accompanying temperatures. It has been shown that internal temperatures vary widely in homes (Huebner et al, 2013), show distinct temporal patterns (Huebner et al, 2015b), and do not map on temperatures expected at certain times in building stock models (Huebner et al, 2013). However, these temperatures have not been mapped onto thermal comfort experiences.

In particular, this paper aims at answering the following questions.

1. How many households in the UK experience thermal discomfort in the home? (Section 3.1 'Prevalence of thermal discomfort')

2. What household and dwelling characteristics are associated with experiencing thermal discomfort? (Section 3.2

3. Does energy consumption vary between homes experiencing and not experiencing thermal discomfort? (Section 3.3

4. Do average, minimum, and maximum internal temperatures vary between homes where occupants experience thermal discomfort and where not? (Section 3.4 Internal temperatures for comfort / discomfort)

Note that the expression "thermal discomfort" is used for brevity to indicate when someone stated to not be able to keep comfortably warm in winter and having difficulties in keeping rooms cool in summer. The data analysed for this paper were collected as part of the Energy Follow-Up Survey (EFUS), commissioned by the Department of Energy and Climate Change (DECC, 2013), and consist of survey responses, estimated annualized energy consumption, building information, and internal spot temperature measurements.

This paper is organized as follows. First, some further information about the underlying data is provided, and then in turn the four research questions are addressed and as necessary further methods information given.

2 General methods

The 2011 EFUS consisted of a follow-up interview survey of a sub-set of households first visited as part of the 2010/2011 English Housing Survey (DECC, 2013). The English housing survey (EHS) is a continuous national survey commissioned by the Department for Communities and Local Government (DCLG). It collects information about people's housing circumstances and the condition and energy efficiency of housing in England.

The EFUS 2011 face-to-face interview survey was undertaken by interviewers from GfK NOP between December 2010 and April 2011. A total of 2616 interviews were completed, drawn from a sample of addresses provided from the first three quarters of the 2010/11 English Housing Survey (EHS). These data were then weighted to account for survey non-response and to allow estimates at the national level to be produced. Temperature monitoring was done in a subsample of N = 823 homes. Spot temperature measurements were taken every 20 minutes, i.e. from midnight to 23.40h, resulting in 72 measurements per day. The temperature loggers used were modified TinyTag Transit 2 data loggers, produced by Gemini Data loggers. Householders were instructed on how to place them in the house (e.g. away from direct sunlight); for details see (DECC, 2013b). Temperature measurements were taken in the living room, the main bedroom, and the hallway.

Finally, meter readings were obtained in a sub-sample of 1345 homes and annual gas and electricity consumption calculated.

The exact items to elicit judgements on thermal comfort / discomfort were:

- During the cold winter weather, can you normally keep comfortably warm in your living room? (response options: yes, no)

- During a typical summer (June to August), do you find it difficult to keep this room

cool – [Living room / main bedroom / other bedrooms / other - specify]?

3 Research questions: Results

3.1 Prevalence of thermal discomfort

Across the total sample of the EFUS (N = 2616), 174 householders (6.7%) reported that during cold winter weather, they normally cannot keep comfortably warm in the living room. The main reasons for this were that it was not possible to heat the room to a comfortable standard (N = 92) and that the costs of keeping the heating on were too high (N = 48).

N = 240 householders (9.2%) reported that during a typical summer, they find it difficult to keep the living room cool, and N = 295 (11.3%) of householders reported difficulties in keeping the main bedroom cool. Householders were also asked about other rooms; the individual cases are too small for meaningful analysis as 12 different rooms were mentioned; however, across the sample, N = 539 households reported that at least one room would get uncomfortably hot, i.e. 20.6% of all households. Hence, not being able to keep rooms cool in summer was more prevalent than not being able to keep comfortably warm in winter.

3.2 Household and dwelling characteristics associated with thermal discomfort

For analysis of factors associated with thermal discomfort, only homes that had reported no change in dwelling or household characteristics since the last EHS were considered (as these changes were not carefully documented) and for which energy consumption data was available. This left N = 1000 homes. N = 58 of those reported that they were unable to keep their living rooms comfortable warm in winter. N = 78 and N = 108 respectively, reported not being able to keep the living room or bedroom cool in summer. Whilst these case numbers are relatively small, they allow quantitative statistical analysis. Three multivariate logistic regression analyses were used to characterize homes that experience thermal discomfort (not being able to keep living room comfortably warm in winter, not being able to keep living room cool in summer, not being able to keep bedroom cool in summer) as opposed to those that did not report any issue. Binary logistic regression has a categorical outcome variable (in this case, reporting discomfort or not), and the aim is to predict the probability of belonging to either one category given certain values on the predictor variables. The logistic regression coefficients give the change in the log odds of the outcome for a one unit increase in the predictor variable. Table 1 summarizes the variables used as predictors in the logistic regression (for more details, see Huebner et al, 2015a). Reference category is indicated in bold. HRP stands for ‘Household Reference Person’ which refers either to the sole owner or the tenant of a property, or, if there is more than one occupant, the person with the highest income, and in the case of equal incomes, the oldest of those (ONS 2012).

Table 1. Frequency / summary statistics of the predictor variables.

Variable (abbreviation)	Categories (N)
Floor area (FloorArea)	n/a (continuous: M = 90.8m^2, SD = 43.05)
Dwelling type (DwType)	Converted & purpose built flat (157), **detached** (234), end terrace (120), mid- terrace (183), semi-detached (306)
Number of storeys (NoStorey)	n/a (continuous: M = 2.14; SD = 0.95)
Government Office Region (GOR)	**East (110),** East Midlands (68), London (108), North East (74), North-West (178)), South East (135), South-West (96), West Midlands (98), Yorkshire and the Humber (133)
Dwelling age (DwAge)	**pre 1919** (142), 1919-44 (171), 1945-64 (230), 1965-80 (236), 1981-90 (79), post 1990 (142)
Wall type (WallType)	9-inch solid wall (139), cavity uninsulated (302), **cavity with insulation** (489), other (70)
Double glazing (DblgGlaz)	**entire house** (795), more than half (117), less than half (38), no double glazing (50)
Attic (Attic)	Yes (106), **no** (894)
Conservatory (Conservatory)	Yes (195), **no** (805)
Main heating fuel (Fuel)	electrical system (50), **gas system** (950)
SAP rating (SAP)	**B& C** (138), D (557), E (256), *F*&G (49)
Number of occupants (HHSize)	n/a (continuous: M = 2.37, SD = 1.26)
Age of youngest dependent children (DepChild)	**No dependent children** (687), 0-4 years (131), 5-10 years (88), 11-15 (64), older than 16 (30)
AHC (After-Housing-Costs) equivalised income quintiles (Income)	1st quintile – lowest (149), 2nd quintile (220), 3rd quintile (210), 4th quintile (211), **5th quintile- highest** (210)
Tenure (Tenure)	Local authority (120), **owner occupied** (635), private rented (102), Registered Social Landlord RSL (143)
Sex of HRP (SexHRP)	**Female** (394), male (606)
Age of HRP (AgeHRP)	16 - 29 yrs (52), 30 - 44 (239), 45 - 64 (407), **65 or ove**r (302)
Employment status of household (EmployHH)	1 or more work full time (485), 1 or more work part time (86), none working and none retired (101), none working, one or more retired (328)
Someone in household sick or disabled? (Sick/disabled)	**No** (649), yes (351)
Someone in household over 75 years? (over75)	**No** (876), yes (124)
Length residency (LengthRes)	**2 yrs or less** (171), 3-4yrs (117), 5-9years (198), 10-19 (218), 20-29 (134), 30+years (162)

Income was coded as equivalized income, meaning that household incomes were adjusted for household composition and size such that those incomes can reasonably be directly compared with each other. This implies increasing the incomes of small households and decreasing the incomes of large households and the extent of these increases and decreases is determined by an internationally agreed set of scales. Equivalized income was chosen as it is considered to provide a better indication of household disposable income

3.2.1 Predicting winter discomfort living room

The outcome variable was whether householders reported that they could keep comfortably warm in the living room in winter ('no' coded as 1) or not (coded as zero). Table 2 summarizes the results; for brevity, only significant predictors are listed

Table 2. Winter discomfort – results of logistic regression.

Predictor	*B*	*SE*	*p*	*Odds ratio*
Walltype cavity uninsulated (Ref = Cavity insulated)	0.88	0.411	.031*	2.418
Dbglz: less than half (Ref = whole house)	2.18	0.671	0.001**	8.799
Equivalized income: 5th quintile (Ref = lowest)	-1.73	0.798	0.030*	0.177
none working and none retired (Ref = 1 or more full time)	1.19	0.477	0.012	3.295

Pseudo R^2: Hosmer and Lemeshow R^2=0.228; Cox and Snell R^2= 0.096; Nagelkerke R^2 = 0.269. Significance levels: $p < .05$ indicated with *; $p < .01$ indicated with **

Note that odds-ratios are always positive values. The distinction regarding a positive or negative relationship in the odds ratios is given by which side of 1 they fall on. 1 indicates no relationship. Less than one indicates a negative relationship and greater than one indicates a positive relationship. Also note that for categorical predictors, the estimates refer to the comparison of the respective category and the reference category. The odds of experiencing thermal discomfort in winter in the living room are 2.418 higher when living in a dwelling with an uninsulated cavity wall as opposed to an insulated cavity wall. Having less than half of double-glazing as opposed to full double-glazing is associated with increased odds of 8.799. Being in the highest income class as opposed to the lowest decreases the odds of experiencing thermal discomfort. 'None working and none retired' is associated with an increased risk of experiencing thermal discomfort (as opposed to at least one working full time).

3.2.2 Predicting summer discomfort living room

Here, the outcome variable was whether householders complained about not being able to keep the living room cool in summer.

Table 3. Summer discomfort living room – results of logistic regression.

Predictor	*B*	*SE*	*p*	*Odds ratio*
GorEHSEast Midlands(Ref= East)	1.46	0.701	.036*	4.319
GorEHSYorkshire and the Humber (Ref=East)	1.45	0.622	.020*	4.272
1 or more work part time (Ref = 1 or more full-time work)	0.86	0.434	.030*	2.357
Sick / disabled (Ref = No)	0.70	0.297	.018*	2.020
Length residency 20-29 years(Ref = 2yrs or less)	1.69	0.579	.003**	5.425
Length residency > 30 years (Ref = 2yrs or less)	1.65	0.606	.007**	5.188

Pseudo R^2: Hosmer and Lemeshow R^2=0.186; Cox and Snell R^2= 0.097; Nagelkerke R^2 = 0.229. Significance levels: p < .05 indicated with *; p < .01 indicated with **.

The significant effects point towards some characteristics of vulnerability of householders who do experience thermal discomfort in summer; i.e. those saying that there is someone sick or disabled in the household have higher odds of reporting thermal discomfort, as do those who have lived somewhere for a long time which is likely to be older residents.

3.2.3 Predicting summer discomfort bedroom

Finally, experiencing thermal discomfort in the summer in the bedroom was the dependent variable.

Table 4. Summer discomfort main bedroom – results of logistic regression.

Predictor	*B*	*SE*	*p*	*Odds ratio*
Dwelling age post 1990 (Ref= Pre 1919)	1.42	0.616	.021*	4.129
Household size	0.27	0.128	.033*	1.311
Dependent children 5-10 years (Ref = none)	-1.02	0.516	.049*	0.3619
Age HRP 16-29 (Ref = over 65)	1.97	0.728	.007**	7.152
Age HRP 30-44 (Ref = over 65)	1.40	.628	.026*	4.053
Length residency 20-29 (Ref = 2 years or less)	1.04	0.496	.036*	2.835

Pseudo R^2: Hosmer and Lemeshow R^2=0.139; Cox and Snell R^2= 0.091; Nagelkerke R^2 = 0.183. Significance levels: p < .05 indicated with *; p < .01 indicated with **.

Results are somewhat harder to interpret. In terms of building characteristics, the finding that the most modern buildings have a greater chance of overheating than old dwellings makes intuitive sense given that modern buildings have higher levels of insulation and such buildings are prone to overheating unless care is taken in the design to prevent this. However, why younger people should be more affected than older is unclear clear.

3.3 Differences in energy consumption depending on comfort reporting

Ordinary least squares regression (OLS) was used to see if thermal comfort vs. discomfort would have an impact on annual energy consumption. The dependent variable was annualized total energy consumption (winter discomfort) or annual electricity consumption (summer discomfort); all predictors were used as in 3.2 with the added predictor of thermal comfort / discomfort which was dummy-coded, with the reference category being thermal comfort (i.e. thermal discomfort was coded as 1). One might speculate that those not being able to keep comfortably warm in winter will heat more and hence have higher energy consumption, and those who experience thermal discomfort in summer (i.e. not being able to keep cool in summer), will use air-conditioning and hence have higher electricity consumption. Note that for brevity only the overall result of the regression is reported together with more detailed information for the comfort predictor. For general findings on what predicts energy consumption, see e.g. Huebner et al (2015b).

In the first OLS, annualized energy consumption was the dependent variable, and reported thermal discomfort in winter in the living room the crucial predictor of interest. Whilst the overall model was highly significant [$F(58, 941) = 9.51$, $p < .001$] and explained $R^2 = 36.96$ of the variability in energy consumption, the predictor "thermal discomfort" was not significant, $t = 0.758$, $p = .449$.

In the second OLS, annualized electricity consumption was the dependent variable, and reported thermal discomfort in the living room in summer the predictor of interest. The overall model was significant, $F(58, 941) = 3.04$, $p < .001$, $R^2= 15.77$; however, the predictor of thermal comfort was not significant, $t= -1.03$, $p = .304$. The final OLS looked at summer discomfort in the bedroom; again, the predictor of thermal discomfort was not significant, $t=-0.21$, $p = .831$; with the overall model being significant, $F(58, 941) = 3.02$, $p < .001$, $R^2= 15.68$.

Hence, there is no indication of differences in energy or electricity consumption, respectively, for householders experiencing winter or summer discomfort, and those who do not. This analysis is controlling for other predictors (as detailed in 3.2).

3.4 Analysis of temperature data

The exact time period when temperature measurements were taken during EFUS varied slightly from home to home depending on sensor instalment; however, as the EFUS report itself used measurements in the time period from February 2011 until January 2012 for analysis the same was done here (even though that meant that some homes were excluded).

The question about not being able to keep warm in the living room was phrased as "during the cold winter weather"; here, the months February 2011, December 2011, and January 2012 were taken as winter months. For summer overheating, the months June, July, August were specified as the period under consideration, all from the year 2011.

3.4.1 Winter discomfort

For N = 53 households that reported feeling too cold in the living room in winter (initially, 55, but two exhibited faulty sensor readings), and for N = 735 who were comfortable in winter in their living room, temperature data were available.

For each household, we first calculated the average daily temperature over the winter period in the living room. We then used boxplot analysis to identify outliers in the average daily temperatures. This was done to capture and remove those days where the house was likely to be unoccupied. An outlier is defined as a data point that is located outside the whiskers of the boxplot (i.e.: outside 1.5 times the interquartile range above the upper quartile and below the lower quartile).

3.4.1.1 Variability within and between homes

Temperatures varied greatly between homes, and to a significant extent also within homes.

Figure 1 shows the daily temperature profile for the living room in one house [i=54, T228.txt] where each line represents one day.

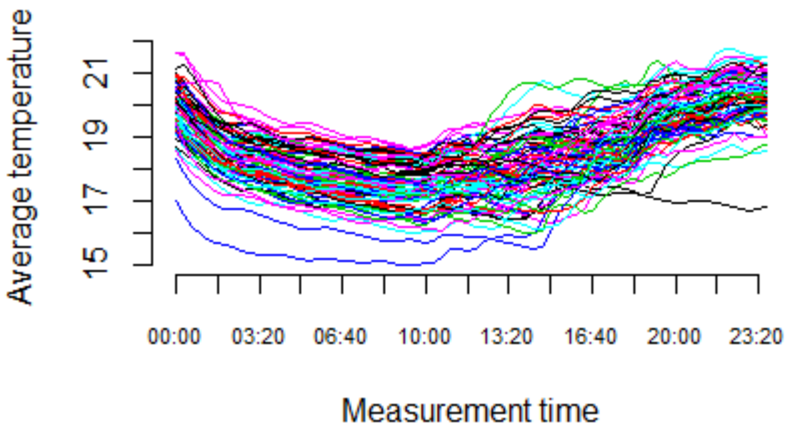

Figure 1. Day to day variability of internal temperature in one home.

Figure 2 shows average winter temperature profiles for those experiencing cold thermal discomfort with each line representing one house.

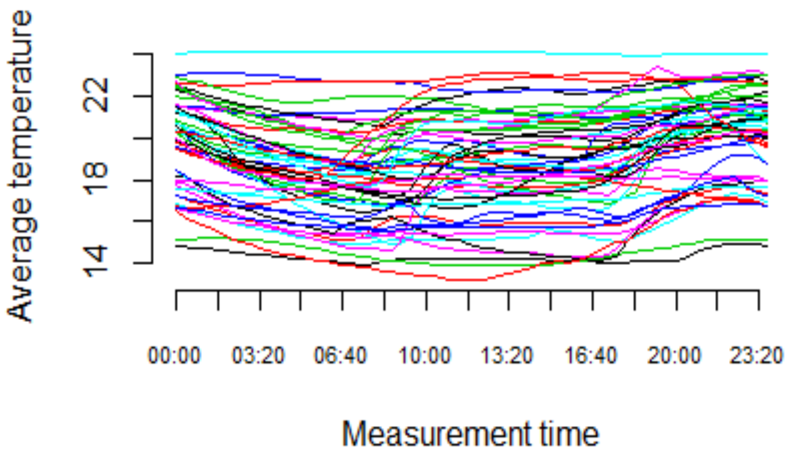

Figure 2. Average winter temperatures for homes not being able to keep comfortably warm in winter.

For homes not experiencing thermal discomfort, similar variability is observed (however, a plot would be illegible because of the number of properties).

As a way of quantifying the variability, we calculated the standard deviation of temperature measurements for each day. We then averaged these values across all days for each home. One might expect that a household in which thermal discomfort is experienced, sees greater variability in daily averages as the house presumably will vary to a greater extent with varying external conditions, including days where the heating system will not cope in bringing the room temperature up to desired levels.

For those experiencing thermal discomfort, the average standard deviation across homes was $M_{discomfort}$ = 1.16. For those not experiencing thermal discomfort, the average standard deviation across homes was $M_{comfort}$ = 1.28. This difference was not significant as shown by an Welch 2-sample t-test, $t(63.34) = 1.64$, $p = .105$) but if anything the trend goes towards larger standard deviations in the sample not experiencing thermal discomfort.

3.4.1.2 Average winter temperatures

First, we calculated the average winter temperature in each house, i.e. we averaged temperatures across each day, and then averaged these 90 values to arrive at one single estimate of the internal temperature at the sensor. Averaged across all homes experiencing discomfort, the mean temperature was $M_{discomfort}$ = 19.03 (SD = 2.26). Averaged across all homes not experiencing thermal discomfort, the mean temperature was $M_{comfort}$ = 19.00 (SD = 2.46).

An independent samples t-test showed that this difference was not significant, t (62.59) = -0.09, p = 0.927. Hence, those reporting thermal discomfort did on average not have lower indoor temperatures in the living room.

We then looked at average day-time temperatures, with day being defined as 7 am to 22 pm. The average temperature across homes and days was $M_{discomfort}$ = 18.95 (SD = 2.35), and $M_{comfort}$ = 18.93 (SD = 2.51), the difference again was not significant.

Note that whilst it might be surprising that day time temperatures are not higher than whole day averages, this is explained when looking at the temperature profile (Figure 3). Temperatures rise almost continuously until about 23.00; and then take some time to fall off, reaching a low point in the morning, i.e. average day time temperatures will not be higher than during the rest of the period.

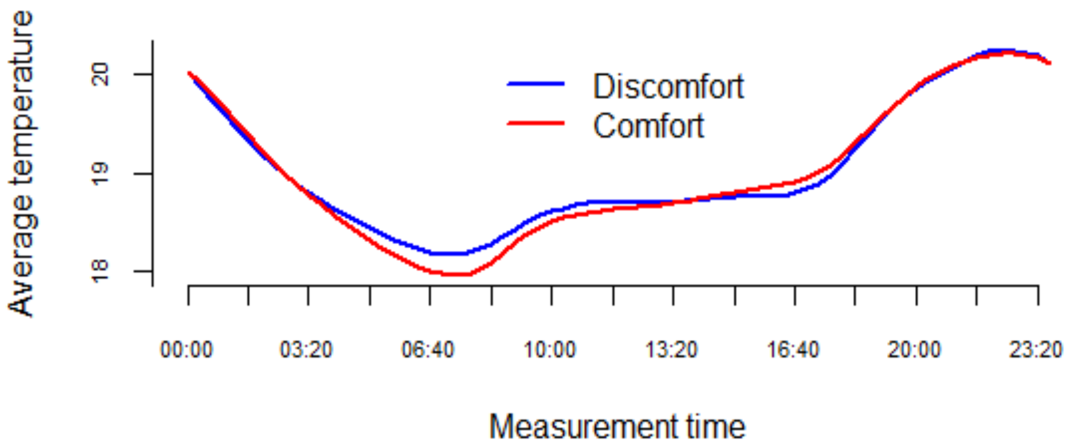

Figure 3. Average temperature profile for households experiencing thermal discomfort (blue line) and those not (red line).

Figure 3 also reinforces the point that average temperatures do not differ for homes experiencing thermal discomfort and those that do not.

3.4.1.3 Ten coldest days

For each home, we calculated the average internal daily temperature across the 72 measurements per day. We then selected those ten days with the lowest average internal temperature. Figure 4 shows the histogram of those for homes that complained about not being able to keep their living room warm in winter (blue), and those who did not (red).

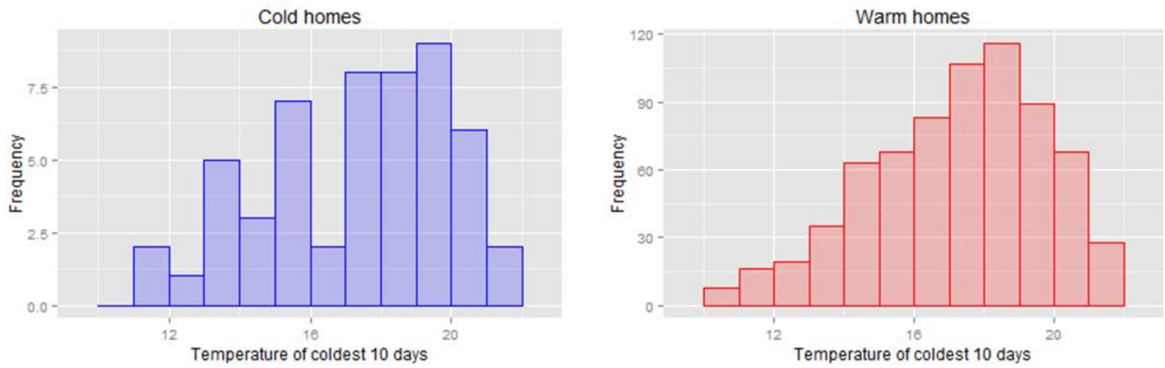

Figure 4. Histogram of average temperature of coldest 10 days.

Across all 53 'discomfort homes', the average of the 10 coldest days was $M_{discomfort}$ = 17.46 (SD = 2.72). For those homes not experiencing thermal discomfort, the average of the coldest 10 days was $M_{comfort}$ = 17.28 (SD = 2.86); again, this difference was not significant (independent samples t-test, $t(61.97) = -0.49$, $p = 0.627$). Hence, it was not the case that those experiencing thermal discomfort experienced lower temperatures on the ten coldest days inside.

3.4.2 Summer discomfort

N = 68 reported finding it difficult to keep their living room cool in summer, and for those, temperature data was available for 67 homes and temperature data was available for N = 718 did not have such an issue. Note that no outlier detection was performed in summer, as it was assumed that high temperatures in summer were genuine (i.e. whereas in winter outliers at the lower end would indicate a house not being occupied and hence the temperatures not experienced by occupants). This assumption might not always hold given that a house might heat up even more than usually when occupants are away, leaving all windows closed. However, the data do not allow testing for this (whereas in winter, temperature differences are very pronounced between presumably unoccupied and occupied days).

3.4.2.1 Average summer temperatures

The average temperature across homes who experienced difficulties in keeping the living room cool was $M_{discomfort}$ = 20.95 (SD = 1.46), and for those who do not, $M_{comfort}$ = 21.22 (SD = 1.54); difference n.s. This value includes night time temperatures; indicating that day time temperatures might indeed be much higher. We then identified the highest temperature for each day in each house, and averaged this across days for each house. Across homes, this value was $M_{discomfort}$ = 22.47 (SD = 0.14) for homes experiencing discomfort. For those who can keep the living room cool, the average was $M_{comfort}$ = 22.69 (SD = 0.14). This difference was significant, t(80.17) = 12.82, $p < .001$; those not reporting discomfort experiencing higher maximum average temperatures (by numerically 0.2 degrees).

3.4.2.2 Ten hottest days and hottest temperatures

For those stating they find it difficult to keep the living room cool, the average of the ten hottest days was $M_{discomfort}$ = 22.55 (SD = 1.51), i.e. this estimation was based on the average daily temperature of which the 10 days with highest average values were chosen. For homes not reporting comfort issues the mean temperature was $M_{comfort}$ = 22.88 (SD = 1.69). This difference was significant, t(833.35) = 5.29, $p < .001$. Those not reporting comfort issues actually have warmer internal temperatures when looking at the ten warmest days.

We then identified the ten highest maximum temperatures experienced (i.e. the maximum temperatures of 10 distinct days; which were not necessarily the days with the highest average temperature). Here, the mean value was $M_{discomfort}$ = 23.88 (SD = 1.65) for those saying they cannot keep their living room cool. For those who did not report problems with keeping the room cool, $M_{comfort}$ = 24.40 (SD = 1.97). This difference was significant, t(84.54) = 2.43, p = .0173, i.e. those not reporting comfort issues experiencing higher maximum temperatures (Figure 5).

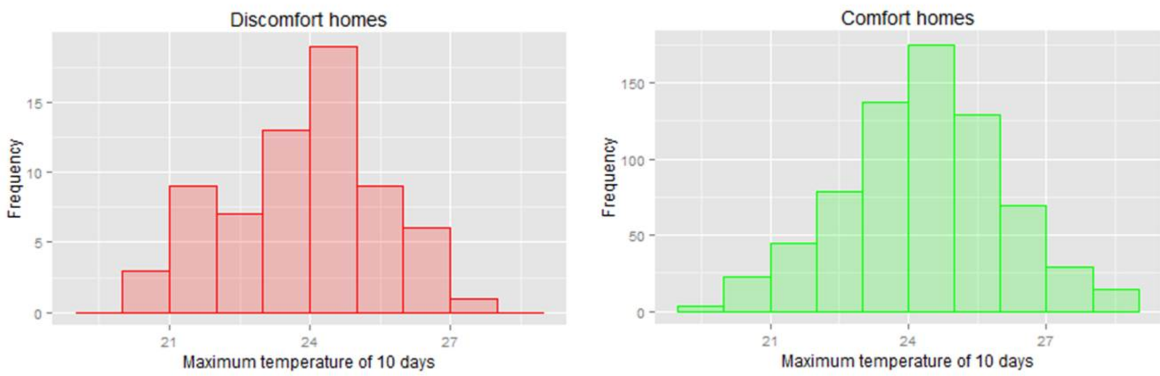

Figure 5. Histogram of maximum temperatures for homes experiencing summer comfort issue (red) and not (green).

It is noteworthy, that some householders stated that they cannot keep their living room cool in summer, yet the maximum temperature experienced was only around 20 – 21 degrees.

4 Discussion

The analysis carried out for this paper showed that a significant proportion of English homes experiences issues with thermal comfort. About 20% in total report not being able to keep cool in summer in at least one room in the home; with about 10% reporting that they cannot keep the living room comfortably warm in winter.

No difference was found in energy consumption for homes that experienced thermal discomfort in winter and those that did not, and in electricity consumption for discomfort in summer. None of the temperature analyses showed that winter discomfort was associated with lower internal and summer discomfort with higher internal temperatures; hence, one might not expect differences in energy consumption.

The finding that statistically similar temperatures were both reported as comfortable and uncomfortable by different participants, could arise from at least three possible causes. It could either indicate that experience of thermal discomfort is strongly dependent on individuals, their characteristics and preferences (as opposed to specific temperatures), or that environmental conditions not directly monitored in the study (such as radiant temperature, exposure to sunlight, experience of draughts, etc.) played an important role. Additional studies assessing such variables would be required to make more definite statements on the extent to which the experienced environments differ for those experiencing thermal discomfort and those that do not. Finally, it might be that the survey instrument was not suitable for best differentiating between those experiencing discomfort and those that do not. For example, the winter question asked whether people can keep comfortably warm in their living room. Given that it was not specified how people kept warm, it might well be that one household reported being able to keep warm and another one that not at the same ambient temperatures if one household used other means to keep warm such as jumpers, blankets, and hot drinks. Hence, specifying the question differently might have led to different findings. Also, the questions for winter and summer differed substantially, i.e. a different construct might have been measured for the two seasons.

Analysis of the temperature data indicated a large amount of variability within and between homes, irrespective of whether thermal discomfort was experienced. This wide variation of temperatures that householders apparently experience as comfortable is reassuring in so far as that acceptable temperatures are not limited to a narrow range. In terms of factors associated with winter discomfort, some variables associated with poorer building quality (non-insulated cavity wall, and not full double-glazing) indicate that building factors do contribute to thermal discomfort and hence buildings ought to be improved. Somewhat worrying is that those in the lowest income quintile are more likely to experience winter discomfort than those in the highest income band. For summer discomfort, effect of predictors varied drastically depending on which room was considered. For living room discomfort, it was more variables that might characterize the occupant as more vulnerable (more likely to be in the house, more likely for those sick / disabled); however, this was not the case for bedroom discomfort. One potential issue with the logistic regressions was the presence of some multicollinearity between predictors which can lead to instable regression coefficients, i.e. it is not clear which variable really had an effect. For brevity, this could not be dealt with in this paper, but see e.g. Huebner et al. (2015a). It might be that when some regression coefficients would change if controlling for multicollinearity.

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