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Overheating in UK homes: Adaptive opportunities, actions and barriers

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Abstract: New-build homes and bungalows are particularly at risk of overheating during hot UK summers. Bungalows are a dwelling type favoured by the elderly who are more vulnerable to the negative health impacts of overheating. Whilst modelling studies have identified overheating risk, monitored data is lacking and limited information about the adaptive opportunities available to households (e.g. ventilation and shading). Even less is known about the adaptive actions taken during hot spells or about the physical, physiological or psychological barriers to acting.

A mixed-method survey tool (OAST) was developed for this study and used to assess overheating occurrence, adaptive opportunities, actions taken and barriers to action. The tool was deployed with a cohort of new-build (n = 4) and bungalow homes (n = 4) in Loughborough, central England.

The survey highlighted potential indicators of overheating risk, including post-occupancy retrofit such as extensions and loft conversions. Occupants' reports provided context and were a key strength of the OAST. Expressed barriers to adaptive action included concerns about security, but there was an inherent lack of concern about overheating and the associated health risks. Recommendations are made for the further development of the OAST as a method of assessing overheating risk in households.

Keywords: Overheating, homes, monitoring, adaptive action, barriers

1. Introduction

There are concerns that as global temperatures increase due to climate change (Cook *et al.*, 2016), an increasing number of UK homes will suffer from summertime overheating (DEFRA, 2017). Homes built after 1990, as well as existing dwellings which will make up 80% of the housing stock in 2050 (RAE, 2010), are prone to overheating (Beizaee, Lomas and Firth, 2013; Lomas and Kane, 2013; Lomas and Porritt, 2017). The problems may be exacerbated if homes are retrofitted to reduce heating energy demands. While studies investigating the effect of design and physical construction on the risk of overheating continue to grow, there is still limited understanding of how people interact with their homes during warm periods, what might drive elected cooling actions, and what the barriers to such actions may be (Mavrogianni *et al.*, 2014).

By 2040, around 25% of the UK population is predicted to be aged over 65 (GOS, 2016; Age UK, 2017). The elderly are most at risk from the negative health impacts of overheating because of their physiological vulnerabilities (Kenney and Munce, 2003; Kovats, Johnson and Griffith, 2006; Vandentorren *et al.*, 2006; DCLG, 2012; Hajat *et al.*, 2014; PHE, 2015; Vardoulakis *et al.*, 2015; Dengel *et al.*, 2016; Lomas and Porritt, 2017). Modelling studies have identified bungalows, a style traditionally preferred by older people, amongst the properties at risk of overheating. This corroborates research by Vandentorren et al. (2006) who concluded that one of the housing characteristics associated with heat-related morbidity was "sleeping on the top-floor, right under the roof" (2006, p. 1), a feature shared by both bungalows and top-floor flats. At present, there is limited evidence from monitoring of bungalows (Vellei *et al.*, 2017) to support these assertions, thus further investigation is essential for better understanding the experiences of bungalow occupants, their responses to high temperatures, and the factors that may constrain the actions they take to reduce the risks to their health.

The absence of mechanisms by which internal temperatures might be lowered, termed *adaptive opportunities*, or limited understanding of how to mitigate elevated temperatures increase the risk to health from high temperatures (Vardoulakis *et al.*, 2015). Recognition of the opportunities for cooling could be integral to an occupant's conceivable adaptive strategies; however, many factors may contribute to what strategies are chosen, which are avoided, and even which might not be identified at all. The adaptive opportunities available may be reduced through dwelling refurbishment. For example, when windows are replaced, the number, and security, of opening windows is often reduced, extensions increase the plan depth, and conservatories block access to outside air. The effects of these changes are exacerbated by higher levels of insulation, which reduces heat loss through the fabric, and reduced background infiltration (Dengel *et al.*, 2016).

The actions that an occupant takes to regulate temperature are termed *adaptive actions*. In free-running dwellings, windows are a key means of reducing indoor air temperature (Nicol, 2001), but utility is dependent on effective use (Palmer *et al.*, 2016). It is recommended that occupants take advantage of cooler night air by opening windows to reduce the temperature of their home (PHE, 2015). Night ventilation requires forward planning which is more difficult for those with cognitive impairment, a condition that is more common amongst the elderly (Lomas and Porritt, 2017). Security risks may also mean that night ventilation is not feasible for those living in bungalows and ground floor flats (Dengel and Swainson, 2012; Mavrogianni *et al.*, 2017; McLeod and Swainson, 2017), and it is likely that a disproportionately high number of elderly people live in ground floor flats and bungalows, the very dwelling type that is most at risk of overheating.

The research reported in this paper sought to understand the incidence of overheating, the factors that were causing it and the actions taken by occupants, why these particular actions were chosen and any barriers to action. In short, the research objectives were designed to further three lines of enquiry 'what can occupants do?', 'what do occupants do?', and 'what do occupants not do and why?'.

Temperatures were monitored during the summer of 2017 in a sample of four new houses and four bungalows in Loughborough in the English Midlands. They included four dwellings occupied by people over 60. The monitored temperatures were assessed against the static overheating criteria defined by the UK Chartered Institution of Building Services Engineers (CIBSE, 2006) and the World Health Organisation (WHO, 1991) as well as the CIBSE adaptive criteria (CIBSE, 2013). A physical survey, to identify the adaptive opportunities, and a semi-structured interview, to understand adaptive actions and barriers, were also undertaken. A new survey instrument was developed for this purpose, the Overheating Adaptive Opportunities, Actions and Barriers Survey Tool (OAST), which is freely available (Wright *et al.*, 2018).

2. Sampling and cohort recruitment

Non-probability convenience and purposive sampling strategies were utilised for recruitment of households because the focus was on developing in-depth home profiles rather than the generalisability of results. The households in the research (n = 8) occupied four post-1990 new build houses, which were recruited from Loughborough University staff, and four bungalows recruited through postal and email advertisements. Eligibility criteria for involvement in the study included a requirement that participants had resided in their home for at least two years and lived in the UK for at least five years. Eleven interviewees from the eight households took part in semi-structured interviews, of which five participants were aged between 61 and 83 (Table 1).

Table 1. Characteristics of each dwelling, the occupants and reported overheating

Case	Type	Total no. of occu-pants	Gender(s) and age(s) of respondent(s)	Occupancy[1]	Tenure	Overheating reported?	Typical Heating Start (month)	Typical Heating End (month)
N01	New Build	2	M (64)	Home/varied	Owner	Yes Utility room	Oct	May
N02	New Build	1	M (30)	Partial/regular	Owner	No	Oct	Apr
N03	New Build	3	M (38) & M (30)	Home/varied	Tenant	No	Oct	May
N04[2]	New Build	2	M (51)	Partial/varied	Owner	No	Oct	May
B01	Bungalow	1	M (70)	Home/varied	Owner	Yes Conservatory	Oct	Apr
B02	Bungalow	2	M (61) & F (62)	Home/varied	Owner	Yes Dining room Main bedroom	Oct	Mar
B03	Bungalow	1	M (83)	Home/regular	Owner	Yes Conservatory	← All Year →	
B04	Bungalow	2	M (41) & F (40)	Partial/varied	Owner	Yes Living room Kitchen Spare bedroom	Sep	Apr

[1] Occupancy was categorised in the following way: Partial/regular = Weekdays approx. 08:30-18:00 all away from home | Partial/varied = Weekdays away from home daily but not fixed times | Home/regular = Regular pattern of up to half-a-day away from home | Home/varied = Irregular pattern of up to half-a-day away from home (Baborska-Narożny, Stevenson and Grudzińska, 2017).
[2] House N04 was not monitored during the hot weather period and data collected are not analysed in this paper.

Nine of the eleven interviewees were male and all homes were owner-occupied except for one (N03). No significant difference ($p = 0.11$) was found between the mean average age of respondents living in new build homes (42) and those in bungalows (60). Occupant ages ranged between 30 and 83 and three households were inhabited by just one person for most of the time (N02, B01 and B03).

3. Methodology

A mixed-methods approach was elected to explore the three research questions (reinterpreted in Table 2). Data collection took place between June and August 2017, and was split across three phases of approximately one month each (Table 3). The surveys were all completed on the initial home visit, and necessary secondary data sources, such as digital maps, accessed after each visit.

Table 2. The research questions and the qualitative and quantitative methods used to investigate each one

Research Question	Methods of investigation
1. What are the designed opportunities for, and barriers to, mitigating elevated indoor temperatures that can be evaluated with a physical assessment?	Building and glazing survey using to create floor plans and layout window schematics to evaluate designed adaptive opportunities and possible barriers to utilisation.
	Dry-bulb temperature monitoring to investigate instances of overheating.
2. How do occupants utilise adaptive opportunities to cool their home in uncomfortably elevated temperatures and what strategies do they utilise?	Semi-structured interview with questions focused on identifying steps taken to cool the dwelling.
	Dry-bulb temperature monitoring to assess impact of actions.
3. What might be the perceived barriers that prevent occupants from utilising opportunities to cool their home?	Semi-structured interview with questions around possible factors that might prevent occupants using a ventilation strategy.

The installations of temperature sensors were staggered across the months of June and July depending on the timing of the home visit. Sensors were placed in the main bedroom and the living room in each household, consistent with previous research (McGill *et al.*, 2016; Baborska-Narożny, Stevenson and Grudzińska, 2017; Gupta, Barnfield and Gregg, 2017; Mavrogianni *et al.*, 2017; Morgan *et al.*, 2017; Symonds *et al.*, 2017; Vellei *et al.*, 2017). Instead of monitoring the designed living room and main bedroom, the functional living room and main bedroom were selected to get a better insight into experienced indoor temperatures. Semi-structured interviews were conducted on both the initial and follow-up home visits. All interviews were recorded digitally, and hand-written notes were made during each interview.

Table 3. Overview of socio-technical procedure for gathering data

Phase One Initial visit (Jun-Jul)	**Phase Two** Intermediate visit (Jun-Aug)	**Phase Three** Follow-up visit (Jul-Aug)
• Interview one • Building and glazing survey	• Temperature monitoring	• Interview two

3.1. The OAST: Physical survey

Data related to the design, layout and features of each participating household as well was occupant experiences and interpretations around the topic of overheating were gathered methodically using the Overheating Adaptive Opportunities, Actions and Barriers Survey Tool (OAST), which was developed specifically for this research (Wright et al., 2018). The items included in the OAST were compiled from the Energy Use Follow-Up Survey (Hulme, Beaumont and Summers, 2013), the English Housing Survey (DCLG, 2015), DEFRA nuisance smells guidance (DEFRA, 2015) and the AECOM guidance for typical noise levels and subjective evaluation (AECOM, 2010) as well as other study-specific items (Table 4).

Detailed schematics of windows and glazed doors (such as patio doors) were recorded. Using the OAST, measurements were taken to be able to calculate the total area, the glazed area, and the operable area (Figure 1). Additionally, windows and doors were surveyed to record: orientation, presence of background ventilation (e.g. trickle vents), opening mode (e.g. casement), presence of blinds or curtains, fixture specifications, glazing type, and security.

Table 4. A summary of data collected using the OAST and means of collection.

Aspect	Element	Measurement method
Geographical, meteorological and situational dwelling data	Proximity of the dwelling to other structures	Secondary data
	Orientation of the designed main façade	Secondary data
	Weather at time of interview	On-site observation
	Distance from a pubic road	Observation
	Shading sources	4-point percentage shading scale
	Possible sources of noise	8-point Likert scale
	Possible sources of smell	8-point Likert scale
Building fabric	Internal structure	Occupant response and observation
	Insulation installed	Occupant response and observation
	Roof type	Secondary data and observation
	Construction date	Occupant response and secondary data
	Heating system	Occupant response and observation
Occupancy details	Duration of occupancy	Occupant response
	Tenure	Occupant response
	Number of occupants	Occupant response
Building use	Frequency of window use	Occupant response
	Typical heating months	Occupant response
Room properties	Ventilation opportunities (passive and active)	Observation
	Room dimensions	Measurement
	Presence of heat generating appliances	Observation
	Floor type	Observation
	Internal door floor clearance	Measurement
Glazing schematics	Aperture area	Measurement
	Free area	Measurement
	Fixture type	Observation
	Blinds	Observation
	Curtains	Observation
	Background ventilator status and dimensions	Observation and measurement
	Security measures (locks)	Observation

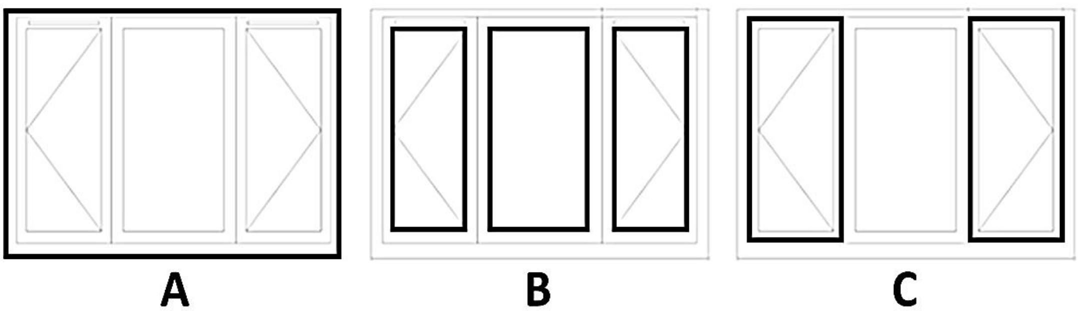

Figure 1. Window and glazed/semi-glazed door details captured in the OAST: total area (A); glazed area (B); and operable area (C)

3.2. The OAST: Monitoring

Taking into consideration the CIBSE TM52 criteria for defining overheating in free-running buildings (CIBSE, 2013), between two and five calibrated Onset HOBO temperature data sensors (UA-001-08 and higher capacity UA-001-64 models) were deployed in each household to log room temperatures from midnight the day after the initial visit (Figure 2). Ten-minute logging intervals were chosen to enable direct comparison with data collected by the weather station located at Loughborough University whilst not overloading the storage capacity of the loggers.

In dwelling N03, data from Secure SES humidity and temperature (reported margin of error ±0.5°C) sensors, which were installed in May 2017 as part of a parallel research project, were utilised to extend the number of days of data. Dwelling N04 was monitored between 5 July and 5 August, but the data are not included in the analysis because the period has limited overlap with data collected in the other dwellings.

Figure 2. Preparing the Onset HOBO temperature data sensors (UA-001-08 and UA-001-64 models)

3.3. OAST: Occupant interviews

A flexible structure was outlined for the interviews to help the conversation to flow naturally (Gray, 2004). The interview topics were focused on investigating the three research objectives. However, the review of literature revealed the importance of including specific prompts to probe topics of interest, for example asking about awareness of temperature control best practice (Baborska-Narożny, Stevenson, & Grudzińska, 2017), about sources of information for combatting overheating (Lomas and Porritt, 2017), and about recognising opportunities for cooling (Meinke *et al.*, 2017).

4. Results

4.1. Incidence of overheating

The UK Met Office heatwave thresholds[1] were not met during the monitoring period (Met Office, 2017). However, between the 16th and the 23rd of June 2017, the average night-time (22:00-07:00) threshold of 15°C for the East Midlands region was exceeded on six consecutive days (Figure 3). As such, this period is called herein a *hot spell*, as opposed to a heatwave. Temperatures monitored during this eight-day period are analysed here. However, sensors had not been located in house N04 by the start of the hot spell, so only the data from the other seven households are analysed.

[1] The UK heatwave thresholds vary by region; the average threshold temperature is 30^{o}C during the day and 15^{o}C overnight.

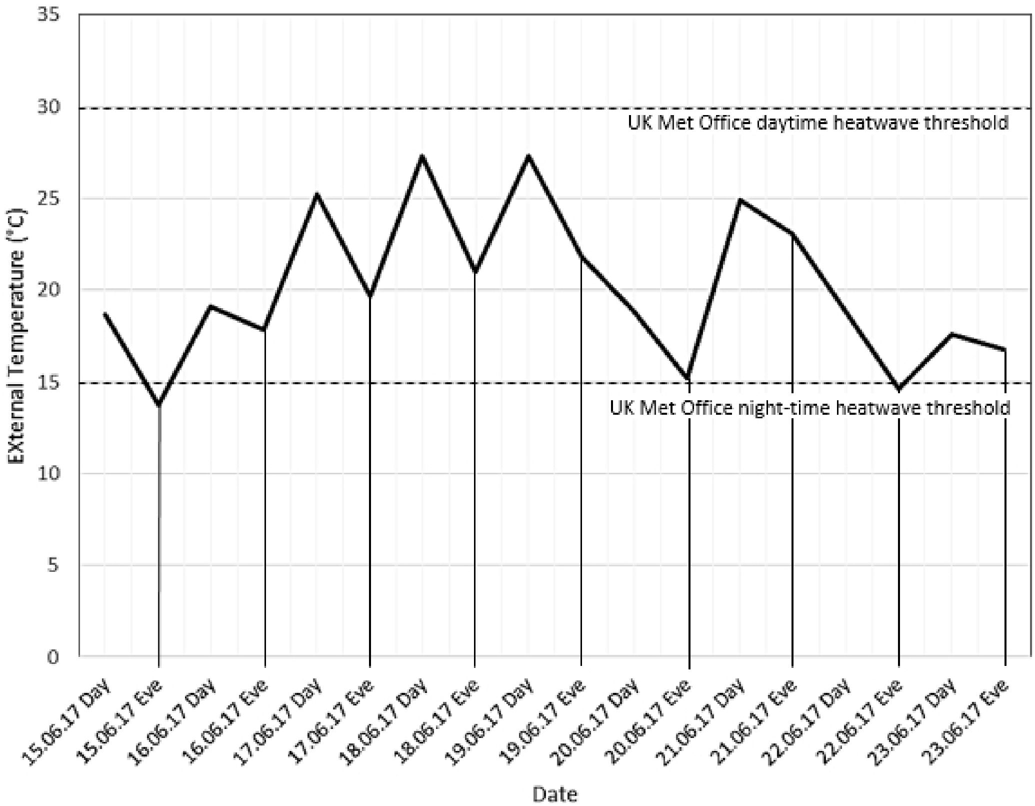

Figure 3. Average daytime (07:00-22:00) and night-time (22:00-07:00) temperatures between 22:00 on the 15th of June 2017 and 07:00 on the 24th of June 2017.

Measured indoor temperatures were collated and processed to calculate temperature exceedance metrics, considering both static (Table 5 and Table 6) and adaptive overheating criteria (Figure 4, Figure 5 and Table 7). Exposure to temperatures above 24°C is considered to be potentially unhealthy (WHO, 1991).

The CIBSE Guide A (CIBSE, 2006) places a 1% limit on the allowable annual exceedance of 28^{o}C in living rooms during occupied hours. In this work the 28^{o}C/1% criterion was applied to the functional living rooms, with occupied hours considered to be all the non-sleeping hours (i.e. 07:00 to 22:00), which is in line with the recently published CIBSE Technical Memorandum (TM) 59 (CIBSE, 2017). Overheating was deemed unacceptable if 28^{o}C was surpassed for more than 54 hours, which is approximately 1% of total annual hours. The same Guide places an annual 26^{o}C/1% limit on bedroom temperatures, a limit which is retained in TM59. For bedrooms occupied from 22:00 to 07:00, this equates to 33 hours annually.

No significant difference was discovered between the mean, maximum and minimum temperatures monitored in the new builds and bungalows (Table 5). During the eight-day hot spell, temperatures during the daytime exceeded 24°C in the functional living rooms for between 62% and 99% of hours. The functional living room in bungalow B03, which was a conservatory, was overheated most of the time, exceeding 28^{o}C for 79% of the daytime hours (i.e. for 89 hours). This space would be considered as overheating by the CIBSE 28^{o}C/1% criterion even if the temperature never exceeded 28^{o}C during the rest of the year. The living rooms of three other dwellings (B01, N03 and N03) exceeded 28°C for between 2% and 11% of daytime hours during the hot spell.

Table 5. Indoor temperatures monitored in the living room during daytime hours (07:00-22:00) between 07:00 on the 16th of June and 22:00 on the 23rd of June 2017.

Case	Room	Temperature (°C) Mean	Max	Min	No. of Hours… > 24°C	> 28°C	% of Hours… > 24°C	> 28°C
N01	Living	26.0	28.9	23.5	99	13	88	***11***
N02	Living	24.7	26.4	22.8	82	0	73	0
N03	Living	25.1	28.7	22.4	85	8	75	***7***
B01	Living	24.6	28.1	22.1	80	2	71	***2***
B02	Living	24.3	28.0	21.6	70	0	62	0
B03	Living*	34.0	58.9	23.7	112	89	99	***79***
B04	Living	24.7	27.8	22.6	78	0	69	0

* The functional living room in B03 was the designed conservatory
Italicised bold indicates failing the CIBSE 28°C/1% limit for the functional living room during the hot spell
Shading indicates failing the CIBSE 28°C/1% threshold for annual overheating hours in the functional living rooms

There was no significant difference between the average main bedroom night-time exceedance hours in the new-build housed or bungalows. Temperatures exceeding 26°C were recorded in the main bedroom of house B03 for 52 hours (Table 6). This is equivalent to 64% of night-time hours over the hot spell, or 1.6% of annual night-time hours, thus indicating that the overheating risk is unacceptably high, even if the temperature never exceeds 26^{o}C during the rest of the year. The second warmest main bedroom, B02, exceeded 26°C for 40% of night-time hours (32 hours total) over the hot spell, equating to 0.97% of annual night-time hours (Table 6).

Table 6. Indoor temperatures monitored in the main bedroom across night-time hours (22:00 and 07:00) between on 22:00 on 15th of June 2017 and 07:00 on 24th of June 2017.

Case	Room	Temperature (°C) Mean	Max	Min	No. of Hours… > 24°C	> 26°C	% of Hours… > 24°C	> 26°C
N01*	Main Bed	-	-	-	-	-	-	-
N02	Main Bed	24.7	27.5	22.8	49	15	60	***19***
N03	Main Bed	24.5	27.9	20.9	48	19	59	***24***
B01	Main Bed	24.6	28.4	21.5	51	20	64	***25***
B02	Main Bed	24.6	32.4	19.0	48	32	60	***40***
B03	Main Bed	26.8	29.8	24.7	81	52	100	***64***
B04	Main Bed	24.4	27.5	22.7	41	11	51	***14***

* The N01 main bedroom sensor failed before the warm spell
Italicised bold indicates failing the CIBSE 26°C/1% limit for the main bedroom during the hot spell
Shading indicates failing the CIBSE 26°C/1% threshold for annual overheating hours in the main bedroom

The adaptive criteria for assessing overheating in naturally ventilated homes, which are defined in CIBSE TM52 (CIBSE, 2013), and retained for living rooms in TM59 (CIBSE, 2017), follow the approach set out in the International Standard BSEN15251 (BSI, 2007). Envelopes of acceptable temperatures, defined by upper and lower thresholds, are set which increase with the running mean of the average daily ambient temperature (Figure 4). The envelopes have different widths applicable to different categories of persons. Cat I, the narrowest band, is applicable to very sensitive and fragile persons with special needs, and thus seems appropriate for assessing the risks of overheating for elderly people (households N01, B02 and B03), Cat III, which is appropriate for existing buildings, was adopted for the other households.

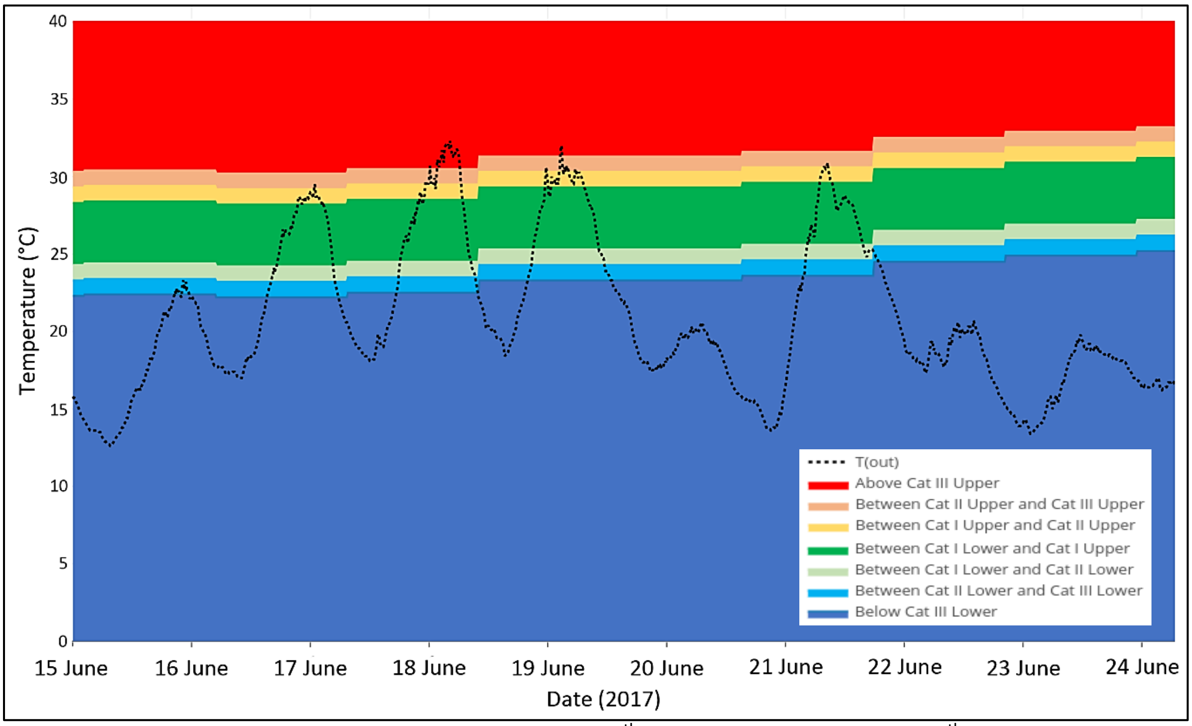

Figure 4. Ambient temperature between 22:00 on the 15th of June and 07:00 on the 24th of June 2017 and the BSEN15251 thresholds for Cat I, II and III.

The percentage of hours during the monitoring period for which daytime and night-time temperatures were within each category envelope are shown in Figures 5 and 6. It is clear that both spaces in the majority of homes were within the Cat I comfort envelope or cooler, suggesting that they were not uncomfortably warm.

The overheating risk in the rooms was assessed using the first of the CIBSE TM52 criteria. This sets a limit of 3% on the number of occupied hours between the 1st of May to the 30th of September for which the operative temperature may exceed the upper category threshold by 1K or more. Here the measured room temperatures were used in place of true operative temperatures.

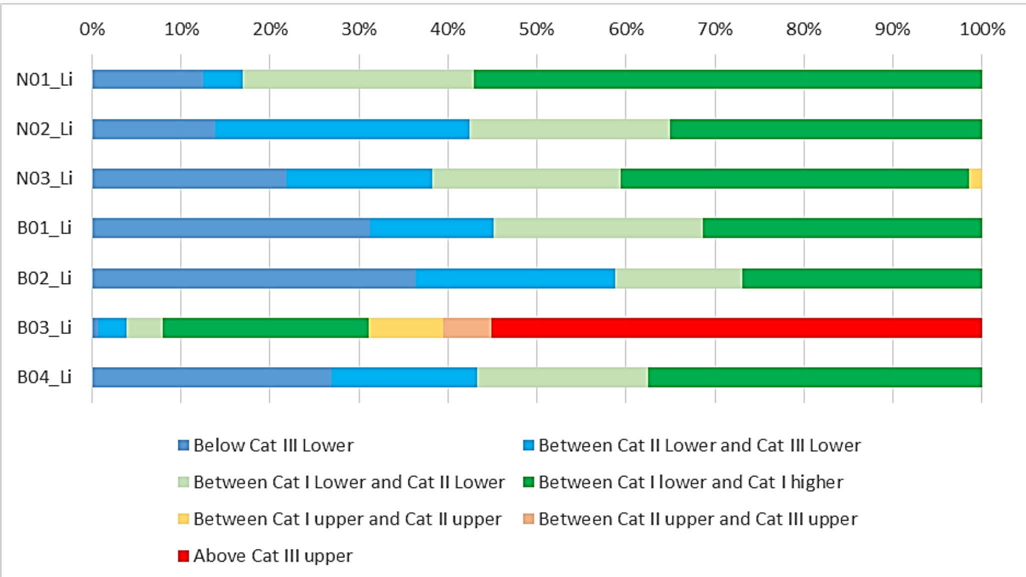

Figure 5. Percentage of time between 07:00 and 22:00 that the temperatures in the functional living rooms lay within the Cat I, II and III envelopes between 07:00 on the 16th of June and 22:00 on the 23rd of June 2017.

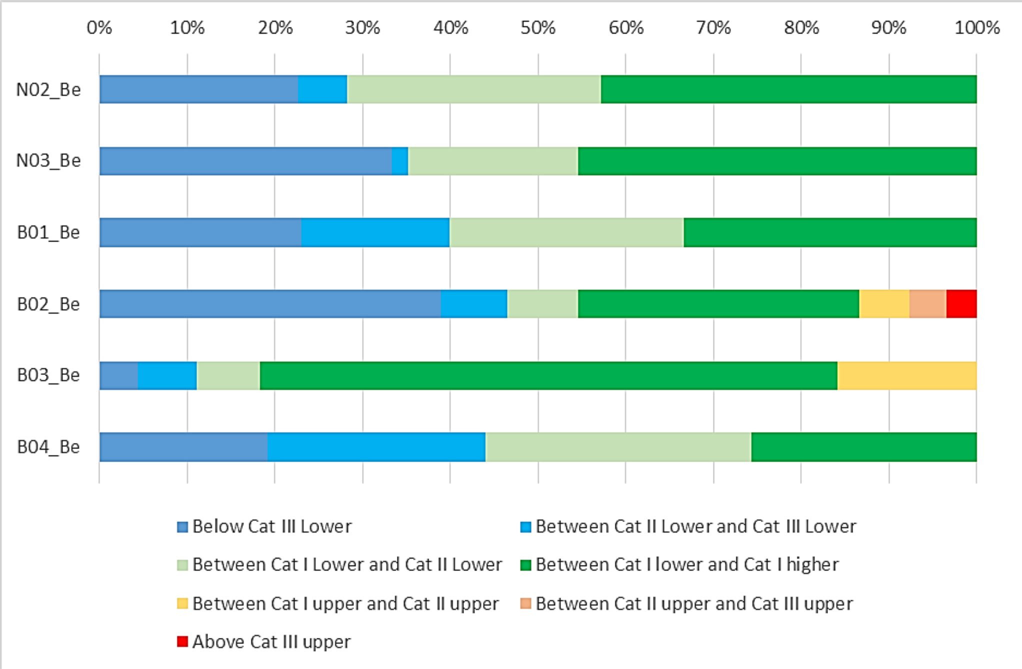

Figure 6. Percentage of time between 22:00 and 07:00 that the temperatures in the main bed rooms lay within the Cat I, II and III envelopes between 22:00 on the 15th of June and 07:00 on the 24th of June 2017.

For the assumed day and night-time occupancy, 3% equates to 3 hours during the hot spell for main bedrooms, 99 hours annually, and 4 hours during the hot spell for the functional living rooms, 164 hours annually. An assessment of monitored temperatures found that, as expected, the functional living room in bungalow B03 (the conservatory) far exceeded the 3% limit during the hot spell, with 72% of hours exceeding the Cat I upper threshold (Figure 5, Table 7). The temperatures in the remaining spaces never exceeded either the Cat I or the Cat II upper thresholds by more than 1K.

Table 7. The daytime hours for which the indoor temperature exceeded the adaptive standard upper threshold by at least 1K in the functional living rooms between 07:00 on the 16th of June and 22:00 on the 23rd of June 2017.

Case	Room	No. of hours above...			% of hours above...		
		Cat I	Cat II	Cat III	Cat I	Cat II	Cat III
N01	Living Room	***0***	0	0	***0***	0	0
N02	Living Room	0	0	0	0	0	0
N03	Living Room	0	0	0	0	0	0
B01	Living Room	***0***	0	0	***0***	0	0
B02	Living Room	***0***	0	0	***0***	0	0
B03	Living Room*	***87***	80	71	***72***	67	59
B04	Living Room	0	0	0	0	0	0

* The functional living room in B03 was a conservatory
Shading indicates a fail at the CIBSE 3% adaptive upper threshold was exceeded by >1K
Italicised bold indicates applicable figure as home occupied by elderly people.

The main bedroom in B02 was also deemed to suffer from overheating, with 12% of available hours exceeding the Category I threshold (Table 8).

Table 8. The daytime hours for which the indoor temperature exceeded the adaptive standard upper threshold by at least 1K in the bedrooms between 22:00 on the 15th of June and 07:00 on the 24th of June 2017.

Case	Room	No. of hours over… Cat I	Cat II	Cat III	% of hours over… Cat I	Cat II	Cat III
N01	Main Bed**	-	-	-	-	-	-
N02	Main Bed	0	0	0	0	0	0
N03	Main Bed	0	0	0	0	0	0
B01	Main Bed	***2***	0	0	***1***	0	0
B02	Main Bed	***9***	4	1	***12***	5	2
B03	Main Bed	***2***	0	0	***2***	0	0
B04	Main Bed	0	0	0	0	0	0

** The N01 Main bedroom sensor failed before the warm spell
Shading indicates a fail at the CIBSE 3%/adaptive upper threshold exceeded by >1K
Italicised bold indicates applicable figure as home occupied by elderly people.

Bungalows B02 and B03 were both occupied by retirees, the Cat I threshold is therefore relevant. The failures against the TM52 criterion suggest that these elderly persons are at more risk of experiencing uncomfortably high indoor temperatures in the summer than the other householders in the cohort. This is particularly concerning given that high temperatures pose a greater risk to health for elderly people.

4.2. Adaptive opportunities

Windows in the dwellings admit sunlight leading to solar gain and so contribute to any overheating risk, but the operable areas within each window, as well as external doors, provide the main opportunity for ventilation cooling. Overall, the bungalows were much more highly glazed than the houses, having glazing-to-floor area ratios between 14% and 32%, compared to 9% to 15% for the houses. The relative area of operable windows and doors in the two dwelling types was, however, similar: 7% to 12% for the bungalows, and 8% to 12% for the houses. If the external doors are excluded, on the grounds that opening them would create an unacceptable security risk, the relative operable areas become: bungalows, 5% to 7%; and houses, 7% to 9%. (The average floor area of the two types of dwelling was similar: 116m^2 for the bungalows and 103m^2 for the houses.) These figures suggest that the bungalows are likely to experience greater summertime solar gains than the houses, yet provide only the same, or less, ventilation opportunity.

To examine the relationship between the incidence of overheating and the solar gain and ventilation opportunities in the functional living rooms and the bedrooms, the glazing-to-floor area ratios (Gla:Flo) and operable area-to-floor area ratios (Ope:Flo) were calculated (Figures 8a and 8b). The very high relative area of glazing (47% of floor area) yet much lower operable area (12% of floor area), in the living room of bungalow B03, may well explain the overheating that was observed (Figure 5 and Table 7). House N03 also has a high glazed area but low, 4%, operable area (cf. Figure 5). The overheating in the bedroom of bungalow B02 may also be due to the high relative glazed area (21%) but limited operable area (4%).

The windows in bedrooms B01 and B03 actually faced onto conservatories (e.g. Figure 9), and so the opportunity to ventilate these two spaces with external air was very limited indeed.

In newly built houses, trickle vents provide background ventilation, and were present in the windows and patio doors of all the houses surveyed, there were no trickle vents in the bungalows. Trickle vents provide limited ventilation cooling capability however. The utilisation of designed opportunities for cooling was explored further through the semi-structured interviews that were part of the OAST.

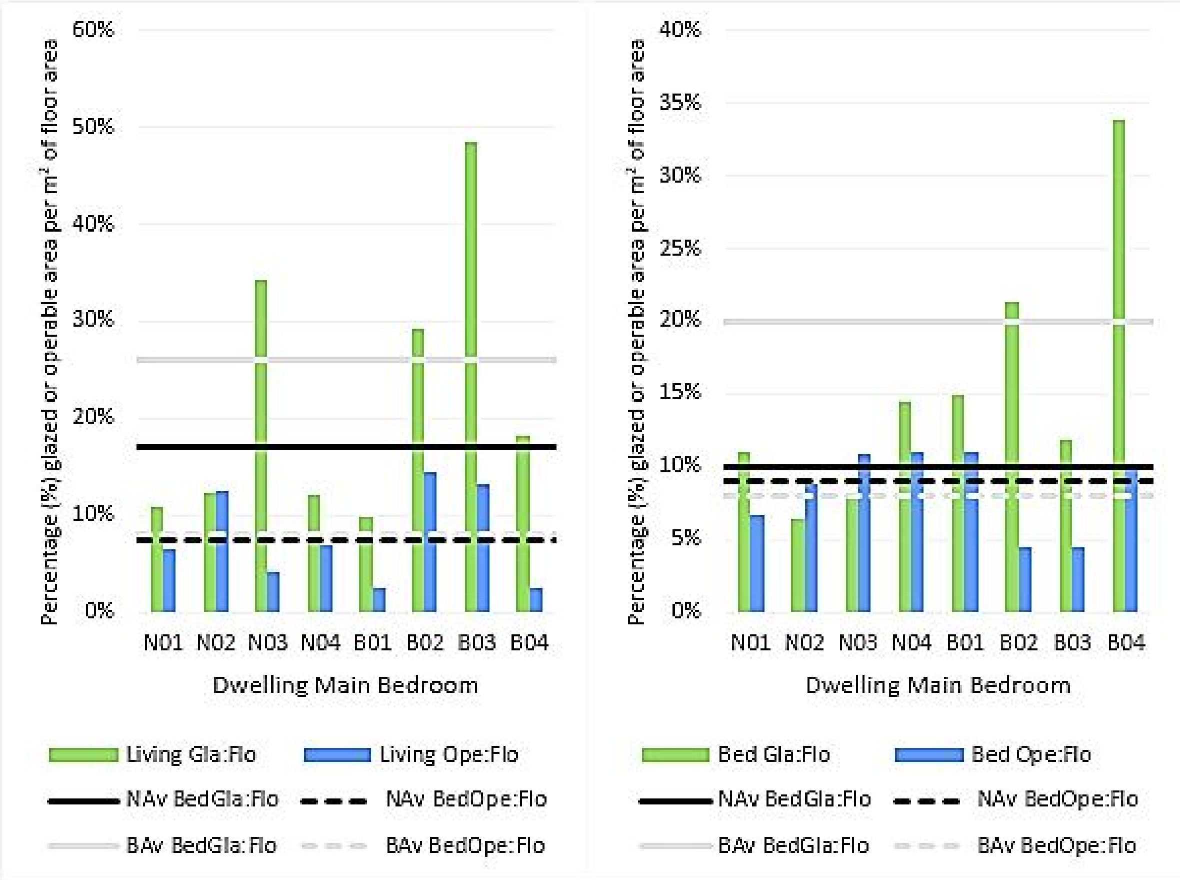

Figure 7. Comparison of the relative glazed (Gla:Flo) areas and relative operable window areas (Ope:Flo), in the functional living rooms and main bedrooms of each bungalow and house

Figure 8. The main bedroom window in bungalow B03 faces directly into the conservatory, which acted as the functional living room.

4.3. Occupant interviews about overheating

In the semi-structured interviews, all the bungalow respondents reported overheating. In contrast, uncomfortably elevated temperatures were only reported for one new house (N01). The interview respondents from houses (N02 and N03) were considered experts in the control of indoor temperature and so were perhaps better placed to achieve a comfortable indoor environment. The interviews with the households living in homes that suffered from overheating are of particular interest, as they shed light on their experiences and the actions they take to try to stay cool.

For the couple living in bungalow B02, the overheating in the main bedroom meant "*sleeping is trickier*". Their bedroom was located in the partially converted loft, which had south-west facing glazing with limited operable area and was equipped with an electric fan. During the day, the windows were the primary means of keeping the bedroom cool, however, when they "*weren't in and* [they] *weren't able to leave the windows wide open*" perceived temperatures were "*up to mid-30s*". If the temperatures were uncomfortably high while trying to sleep, "*the window gets thrown wide open and the duvet gets thrown off*". Rather than using the fan if it was too hot, they would "*probably just move"* to an alternative room such as "*the front bedroom where it's much cooler*". They remarked that they were "*both a bit skinny*" to use the fan, alluding to the uncomfortable breeze that it created. The occupants of house N01 overcame their fan's chilling effect by using "*a very thin cotton cloth for when it's too hot to have the duvet cover over the top …… just enough to keep the breeze off"*.

The adaptation of moving to a cooler location, even at night, is an opportunity limited to households with sufficient space. The literature recognises that overcrowding in homes is linked to higher internal gains and increased risk of overheating (Vellei *et al.*, 2017), and could also mean a reduction in adaptive opportunities for occupants.

Bungalow B03 was occupied by an elderly man. He considered his conservatory to be "*the ideal room to be in when the sun is shining"* and he would spend most of his time in it whilst at home. Upon experiencing uncomfortably high temperatures, the first thing he would do was to "*make sure the heating's off*". Two of the other households (B02 and N03) also sought to reduce sources of heat as their first action, for example, by turning off electrical appliances.

Getting "*as many windows open as possible*" was a common response to uncomfortably high temperatures for all the households interviewed, however, only two households used a specific premeditated ventilation strategy to maximise cooling. One of the occupants in bungalow B04 noted that, *"if it gets really hot, we open the front door, because then you get a nice through-draft. I think it's made a big difference."* Whilst premeditated, this is still a reactive tactic in response to elevated indoor temperatures, rather than a forward-thinking tactic designed to prevent overheating in the first place.

4.4. Barriers to actions

In every discussion around the use of windows, security was raised as a reason to not utilise the adaptive opportunity they afforded. For example, the elderly occupant of bungalow B01 was "*always concerned about somebody coming in… with it being a bungalow… I don't know if they could get in through the windows as they are, as they're quite small gaps, but you always wonder… I'd like windows open through the night, but I'm reluctant to leave an open window when I'm out… I don't like to do it in the day*." Likewise, the elderly occupant of bungalow B03 reported that he "*always* [closed] *the door* [in the conservatory] *and that's for security reasons*". However, concerns about safety and security were not restricted to elderly bungalow occupants, for example the young man that occupied house N02 rarely left open the kitchen window open, which would have been useful for creating a through-draft, because, "*somebody can get inside through the kitchen window if I leave it open because it's at a low level... I don't feel safe leaving it open and sitting* [in the living room] *or upstairs.*" For the man in bungalow B01, security fears meant that "*unless if it's very hot, I tend not to open the windows, because there's always the danger that you go out and forget that they're open… So, I tend to err on the side of caution and not open them*."

Insect pests were cited by four households as a reason why they might be reluctant to open a window for cooling, particularly at night. For example, the young man in house N02, noted "*when it's warm and I'm sleeping in the bedroom and I would like to keep the window open… sometimes I get flies and mosquitos and stuff… so I tend not to open the window very much.*" Likewise, the occupants of bungalow B04 noted that, "*the only thing that would stop me opening a window would be if a light was on while it was night time, to stop bugs getting in …*".

One barrier to action was cited by many of the interviewees, which is probably more important than all the other factors; the 'scepticism' people felt about the 'issue of overheating'. As an occupant of bungalow B04 put it "*here, we have the sort of heat where people think they should really do something about it, but after a few days it's gone, and it goes to the back of their minds…".* Such perceptions are likely to be widespread in the UK.

Whilst the provision of adaptive opportunities, and advice on how to capitalise on these, would be valuable, overcoming the belief that overheating is not a pressing matter, is more important. It is a barrier to the provision of adaptive opportunity, the taking of effective action, and to effective preparation for the heat waves and warmer summers that are to come as the climate warms.

5. Discussion

The study conducted here was short term and involved a small number of households. Although the detailed results from this research may not be generalisable to the wider UK stock of new houses and bungalows, they do offer some useful insights which could guide future work; not least, because the study succeeded in capturing data about overheating during a particularly hot spell of English summer weather.

The rich case studies were developed for each dwelling using the range of data collected through the OAST, which included floor layouts, glazing schematics, occupant information and interview transcripts. The data facilitated the investigation of what people do to cool overheated homes in the summer, enabling three lines of enquiry, 'what can occupants do?', 'what do occupants do?', and 'what do occupants not do and why?'.

Previous modelling research (e.g. Vellei *et al.*, 2017) and epidemiological data has identified bungalows and living spaces directly below roofs as having an elevated risk of summertime overheating. The observation that the bungalows in this study had larger window areas relative to their floor area than the new build houses, and yet had the same relative operable area for ventilation, is interesting and might point to a further factor contributing to overheating in bungalows.

The incidence of elevated temperatures was assessed using both static and adaptive overheating criteria. The sustained hot weather experienced during the monitoring period meant that the upper threshold of thermal comfort provided by the adaptive approach was higher than the CIBSE static threshold of 28^{o}C, even for Cat I, vulnerable, individuals. The occupant interviews revealed that adaptation in response to elevated temperatures occurred even for sleeping periods, e.g. changing duvets for sheets, the use of fans or moving to another room. As previously observed (Lomas and Porritt, 2017), adaptive criteria seem more appropriate for assessing overheating than static criteria and should be developed for use during the night time sleeping period.

Refurbishment and remodelling have been mentioned elsewhere as potentially exacerbating overheating risk (Lomas and Porritt, 2017). This study provided three concrete examples, all associated with bungalows; the conversion of a roof space into a bedroom, and the addition of conservatories to two dwellings. In all three cases, these were associated with elevated indoor temperatures, either in the space itself, or because the conservatory was a barrier to ventilating the adjacent space. It is clear that modifications, either by the present or previous homeowners, to suite their lifestyle, had had the unintended consequence of exacerbating overheating risk. From a regulatory perspective, this may indicate the need to ensure that post-occupancy developments do not place the dwelling at increased risk of overheating.

Security fears, born of experience or the perception of risk, and the ingress of insects, were reaffirmed as barriers to opening windows and hence to night-time ventilation cooling. Fans were used by some households as an alternative but the turbulent breeze they create was uncomfortable at night. The limited experience that the study participants had had of elevated temperatures, given that heatwaves and hot spells occur only occasionally in the UK Midlands, meant that they had not given much thought to what they might do to tackle overheating. For example, the opening of specific windows to achieve cross-ventilation was rare even though this strategy may have been effective and provided sensory feedback, which could positively reinforce behaviour.

Almost all adaptive actions require some level of physical exertion, and many require cognitive effort. Those who may be most vulnerable to elevated temperatures may be amongst those least able to take action, and also the most disadvantaged in planning actions that require premeditation. They may therefore need support, perhaps by providing passive or active cooling devices, or perhaps by using technology to capitalise on the adaptive opportunities that already exist in their home.

The overarching scepticism about the risks of overheating in the UK is, though, a serious barrier, and one that is likely to be widespread in the UK, but difficult for those concerned with public health to overcome.

6. Conclusions

Summer time overheating in UK homes is increasingly seen as a risk to health and well-being. New build houses and bungalows, a dwelling type preferred by the elderly, who are vulnerable to elevated temperatures, may be particularly at risk.

A small cohort of four houses and four bungalows, located in Loughborough in the English Midlands, were studied during an eight-day hot spell, during the summer of 2017. Four of the dwellings were occupied by people over 60, bungalow B03 by man over 80. Room temperatures were measured and the newly developed Overheating Adaptive Opportunities, Actions and Barriers Survey Tool, OAST, (Wright *et al.*, 2018), was deployed to understand the scope for, and inclination of, households to mitigate high summertime temperatures.

Temperatures were measured in the main bedroom and the functional living room, i.e. the room used daily by the occupants, rather than the builders' designated living room. The main bedrooms in all homes monitored over the hot spell were warm, exceeding 26°C for between 19 and 65 hours during the monitoring period. The bedroom in one bungalow (B03) was so hot that it would fail the CIBSE criterion of 26°C/1% of annual hours, even if no high temperatures were recorded in the whole of the rest of the year. The functional living room in this bungalow was also hot, exceeding the CIBSE 28°C/1% of annual hours criterion. This space was also severely overheated as measured by the CIBSE adaptive overheating criterion. Whilst the bedroom temperatures in all the dwellings might hinder quality sleep, the sustained high temperatures in bungalow B03, which was occupied by the 83 year-old are of most concern.

The OAST proved to be a useful tool for identifying the opportunities and barriers to avoiding summertime overheating. Further work to operationalise the tool could be useful for social care and health professionals and other seeking to protect vulnerable people from the risks of summertime overheating.

The survey revealed that the bungalows had substantially higher glazing-to-floor area ratios than the houses, yet very similar relative areas of operable windows. This could increase their risk of overheating by admitting more solar gain without providing any additional means of summertime ventilation. Post-construction remodelling of three bungalows further increased the risk of overheating. In one bungalow, a roof-space converted to create the main bedroom had inadequate ventilation, and in two others conservatory extensions prevented ventilation of the trapped spaces behind.

Interviews with the occupants identified barriers to the use of windows for summertime night-ventilation cooling. The security risk was the main concern, but the possibility of insects entering the house was also mentioned. However, the overarching barrier was the general lack of concern about summertime overheating. It was seen as an infrequent, short duration and unimportant phenomenon. This perception is, perhaps, the biggest barrier to effective preparation for heat waves, the provision of adaptive opportunity and the taking of effective action to curb summertime overheating.

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