Assessing the occurrence of summertime overheating in occupied and unoccupied low energy homes

Rajat Gupta[1], Matt Gregg[1] and Adorkor Bruce-Konuah[1]

[1] Low Carbon Building Group, School of Architecture, Oxford Brookes University, Oxford, UK
email: rgupta@brookes.ac.uk, mgregg@brookes.ac.uk, nbruce-konuah@brookes.ac.uk

Abstract: This paper presents an empirical study to assess the occurrence and possible causes of summertime overheating in three occupied and two unoccupied low energy dwellings in the UK. All five dwellings are identical in terms of construction and location, but have different occupancy profiles and household compositions in the three occupied dwellings. An interdisciplinary approach is adopted, drawing from building science and social science methods, including monitoring of interior environmental conditions, thermal comfort diaries and interviews with residents. Temperature data from bedrooms and living rooms from the case study homes were analysed for overheating using both static and adaptive thermal comfort analyses methods. The findings suggest that summertime overheating is prevalent across both occupied and unoccupied case study dwellings, although overheating assessment using static criteria found a much higher proportion of the rooms to be overheated than the adaptive criteria. In the dwellings a common finding was that bedrooms were found to be more prone to overheating than living rooms. Since it is likely that methods used to assess overheating will be incorporated into regulations in future affecting the design of housing, it is necessary to deploy passive design strategies to prevent the overheating risk in low energy homes.

Keywords: overheating, code for sustainable homes, post occupancy evaluation, adaptive thermal comfort

Introduction

Despite the relatively mild climate of the UK, concern has increased about summertime temperatures in air-tight low energy houses due to the effects of high temperatures on occupant health (Armstrong et al., 2010). There is in fact growing evidence of overheating in homes, particularly in newer homes built to satisfy more demanding standards of energy efficiency (ZCH, no date). The term overheating is used to describe when temperatures make building occupants uncomfortable or heat stressed. With consecutive days of hot weather (including warmer than average nights), internal temperatures in some homes, particularly newer efficient homes, can start to exceed external temperatures and may no longer provide protection from the heat. These conditions can cause discomfort and heat-related effects on health (Armstrong et al., 2010, Hajat et al., 2014).

Overheating can occur in homes as a result of a number of causes acting alone or in combination. These can include heat gain from high external temperatures, direct solar gain on the exterior surface or penetrating glazing, and internal heat gains. Home characteristics such as dark surface materials, rooms in the roof, skylights, inability to ventilate due to location, predominately dark hard surface surroundings, single aspect flats on upper floors, and orientation that allows late solar gain in windows can all contribute to overheating (Gupta and Gregg, 2012). For more vulnerable occupants, such as infants, the elderly or sick, the risk of severe heat stress, including potentially fatal heat stroke, is greater. To make matters worse, these people are typically at home for most of the day and exposed to peak day temperatures, unlike those who go out to work. The cause of overheating is complex and not a simple measure of maximum temperatures; therefore, long continuous periods of above-average indoor temperatures in homes are used to evaluate this condition.

Much research has set out to establish the risk of overheating by simulating the current and future risk in older dwellings (Gupta and Gregg, 2013) and in newer dwellings (McLeod et al., 2013). A number of studies have also demonstrated present-day monitored overheating or summer 'discomfort' in existing dwellings and newly built dwellings (Sameni et al., 2015) in the UK and abroad, in Denmark (Larsen and Jensen, 2011), Sweden (Ruud et al., 2005) and Estonia (Maivel et al., 2015). Within these studies the propensity to overheat is much greater in newer dwellings, e.g. passivhaus designed dwellings, and particularly in flats. It is important to note that overheating is defined slightly differently from region to region, however, there is roughly an agreement that surpassing hours at 26-27°C is problematic.

To contribute to this body of knowledge, the objective of this study is to investigate the extent of overheating in both occupied and unoccupied dwellings in York, England. The homes are newly-built within the past few years and are built to the highest energy efficiency levels under the UK standards current at the time, i.e. Code for Sustainable Homes Level 4. An interdisciplinary approach is adopted, drawing from building science and social science methods, including monitoring of temperature and relative humidity in the living room and principal bedrooms over August and September 2016, dwelling surveys, thermal comfort diaries and interviews with residents.

Methodology

The study involved five dwellings, three occupied dwellings (H1 – H3) and two unoccupied dwellings which are show-homes for the development (SH1 & SH2). All five dwellings are identical in terms of construction and location, but have different orientations and the three occupied dwellings have different occupancy compositions. Table 1 lists some dwelling characteristics for the homes.

Table 1. Summary of characteristics of the case study dwellings
(N/A indicates where some data were unavailable; EPC = Energy Performance Certificate)

	H1	H2	H3	SH1	SH2
Built form	Detached	Mid-terrace	Semi-detached	Detached	Mid-terrace
Front orientation	East (slightly N)	North (slightly E)	South (slightly W)	East (slightly N)	South (slightly E)
Total floor area	84 m^2	118 m^2	93 m^2	N/A	N/A
Occupants	1 adult	2 adults, 1 child	2 adults, 2 children	No occupants	No occupants
EPC rating	B (81)	B (85)	B (83)	B	B
Air permeability	3.8 $m^3/h.m^2$	3.7 $m^3/h.m^2$	3.8 $m^3/h.m^2$	N/A	N/A

Overheating assessment methods

For the overheating assessment, two methodologies were used. These are the *static method* and the *adaptive method*. The static method defines overheating as when in living areas, 1% of occupied hours is >28°C and in bedrooms, 1% of occupied hours >26°C (Humphreys and Nicol, 2006). The adaptive method is a dynamic threshold based on changes in external temperature which also includes levels of occupant sensitivity. The adaptive method defines overheating as when two of the following three criteria are failed:

1) hours of exceedance, 2) daily weighted exceedance, and 3) upper limit temperature (Nicol and Spires, 2013).

Quantitative data collection and assumptions

The evaluation of overheating risk employed internal and external temperature readings on a quarter-hourly basis using internal and external Onset HOBOs and occupancy hours of the monitored spaces. The monitoring of living rooms and bedrooms of all dwellings took place from August 11th – November 24th 2016. This provided partial data on overheating for the summer; specifically, from August 11th – September 30th. In addition to interior spaces, two exterior data loggers were placed outside of H1 and SH1. The exterior (micro-climate) data were found to follow the same pattern; however, a mean was taken between the two loggers to represent the external condition. Actual occupancy details were not collected, however, assumed occupancy schedules are applied for analysis. Consistency across all dwellings in this way assists in comparing the unoccupied dwellings with the occupied dwellings. It is likely; however, that because there is a very young child living in H2, the occupancy varies from this general assumption. The occupancy hours used were 6:00 – 8:00 and 18:00 – 22:00 for the living rooms and 22:00 – 6:00 for the bedrooms.

Qualitative data collection

For H1 & H2, household surveys, interviews and a thermal comfort diary (H2 only) were employed to collect information on occupants' comfort perception, lifestyle, behaviour, use of windows, appliances, etc.

Table **2**. Interview summary

	H1	H2
Comfort in summer	Summer is comfortable	Hot throughout the house, main bedroom most uncomfortable
Most occupied space	Living room	No comment
Method to keep cool	Open windows at about 25°C (uses digital thermostat to observe interior temperature), shorts and t-shirt, cool drinks	Open windows and trickle vents to cool down the space
Window behaviour	Open windows in all rooms daily when home / do not leave them open when away from home, window trickle vents left open in summer	Windows opened whenever necessary in all rooms; however, living room and second bedroom windows are closed overnight
Ventilation or fans	No ventilation units or fans	No ventilation units or fans
Interior doors	Always left open	Always left open
Blinds	Occasionally used	Occasionally used

Results

Table 3 shows the overall findings with relation to the overheating in the dwellings. All dwellings have some level of overheating according to the static method; however, there were no temperature readings >28°C. No dwellings overheat according to the adaptive method (which requires two criteria to fail). It is important to consider that the adaptive method has been developed in and for non-domestic buildings, though this does not explain its lower sensitivity. However, it is useful to evaluate as it considers more variables and theorises an adaptive response from occupants. Only some bedrooms overheated during (expected) occupied hours of the bedrooms. In the occupied dwellings, only the second bedroom overheats in all three cases. In the show-homes both bedrooms overheat. It is theorised that bedroom 1 in the occupied dwellings do not overheat because the adult(s) (prime occupant) control the windows to alleviate overheating in the space. The antithesis of this is potentially why only the second bedrooms overheat. As the show-homes are not occupied during bedroom occupancy hours, windows are not open; this is why overheating occurs in both bedrooms of two of the show-homes.

Table **3**. Overheating results from 11 August – 30 September
(N = north, E = east, W = west, S = south, +sky = skylight, OH = overheating)

	Room	Window orientation	Static method	Adaptive method (failed)	Occupied hours between 26 – 28°C
H1	Living room	NE / SW	0%	-	0%
	Bedroom 1	NE	0%	-	0%
	Bedroom 2	**SW**	**4% - OH**	-	**7%**
H2	Living room	S	0%	-	**3%**
	Bedroom 1	N / S +sky	0%	-	0%
	Bedroom 2	**S**	**2% - OH**	-	**4%**
H3	Living room	SW / NE	0%	-	0%
	Bedroom 1	NE	0%	-	**1%**
	Bedroom 2	**SW**	**3% - OH**	-	**4%**
SH1	Living room	E / W	0%	-	0%
	Bedroom 1	**W**	**6% - OH**	Criterion 2	**8%**
	Bedroom 2	**E**	**14% - OH**	Criterion 2	**13%**
SH2	Living room	N	0%	-	0%
	Bedroom 1	**S / N +sky**	**2% - OH**	-	**7%**
	Bedroom 2	**S**	**4% - OH**	-	**2%**

The H1 occupant considers the summer conditions in the house comfortable and overheating results reflect this. As there is only one occupant in H1, it is probable that the occupant does not use the 2nd bedroom or experience the overheating in that space. In contrast, the responses from H2 show that the occupant finds it hot throughout the house with the main bedroom, as most uncomfortable. Interestingly, it is the main bedroom which has the highest proportion of lower temperatures than the other rooms; this however, could be the perception before opening windows to ventilate, wherein the measurements show the impact of opened windows. Survey responses may also indicate the thermal comfort opinion of the occupants between these two homes, whereas: H1 begins the heating season in October with a heating set-point of 21-22°C and H2 begins the heating season in November with a heating set-point of 18°C. These findings may suggest that the occupant of H2 has a lower tolerance for higher temperatures.

Thermal comfort diary assessment

Thermal comfort diaries were only completed by H2. The results for the actual mean vote (AMV) and predicted mean vote (PMV) corroborate the previous assumption, that the occupant of H2 may be more sensitive to warmer temperatures than other occupants. This can be seen in figure 1, where the AMV is essentially a two point shift above the PMV.

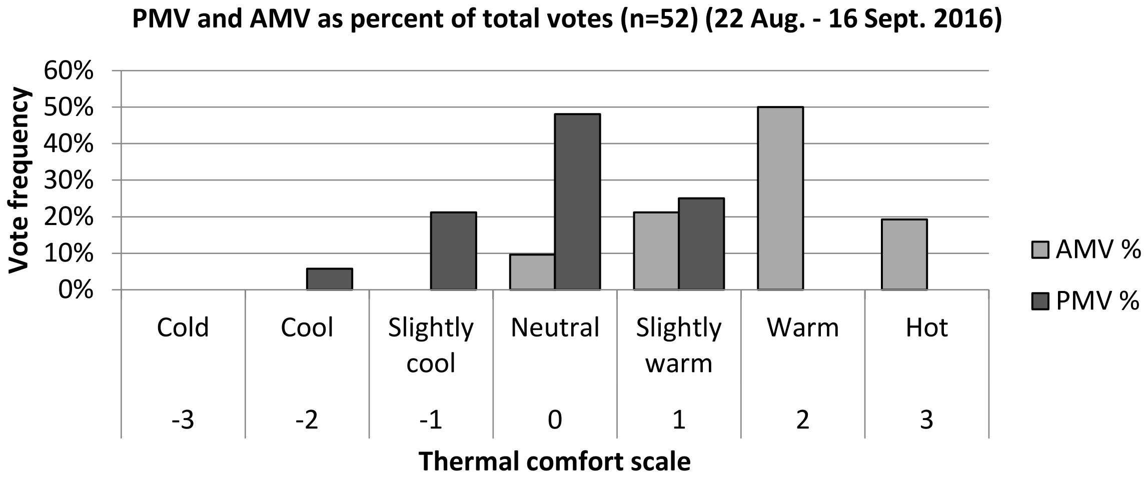

Figure 1. PMV and AMV percentage votes.

Overheating factors

Occupied vs. unoccupied

Neither dwelling type overheats in an overall sense more than the other purely due to occupancy status. This can be seen by comparing SH2 to the occupied dwellings; however, the lack of active ventilating in the SHs is apparent in the bedrooms. Figure 2 focuses on the evening hours to further investigate the difference between the occupied and unoccupied houses. The intent is to observe the dwellings during the 7pm – 7am period, when it is theorised that the show-homes are sealed and unoccupied. As expected, the show homes demonstrate steadier temperature readings due to lack of occupants. A difference between occupied and unoccupied dwellings is difficult to see in the living room, as most dwellings appear to retain similar temperatures and patterns of change during the periods of focus. The bedrooms during this period indicate a different pattern. The occupied dwellings for the most part, appear to be ventilating at night as the temperatures are 1-3°C lower than the show-homes. The tendency for H2 is to exhibit sharp peaks of overheating in response to high temperatures. These sharp peaks were most likely not experienced in the bedrooms as they tend to happen during mid-day when external temperatures were highest and bedrooms are not occupied. According to the interviews, though windows were often used to cool down spaces, windows were not left open when rooms (or the dwelling) were not occupied. SH1, in contrast, retained a steady higher internal temperature though without the sharpness of the peaks. The consistency of the higher temperatures is likely due to the lack of window opening in the show home, particularly in the evening. The remaining dwellings whether occupied or not, appeared to demonstrate a lower level of sensitivity to the external temperature spikes. This may be due to orientation or different space management. Though the dwellings demonstrated the same responsive patterns, overall the temperatures for all dwellings were roughly 2°C cooler in the living rooms than in the bedrooms.

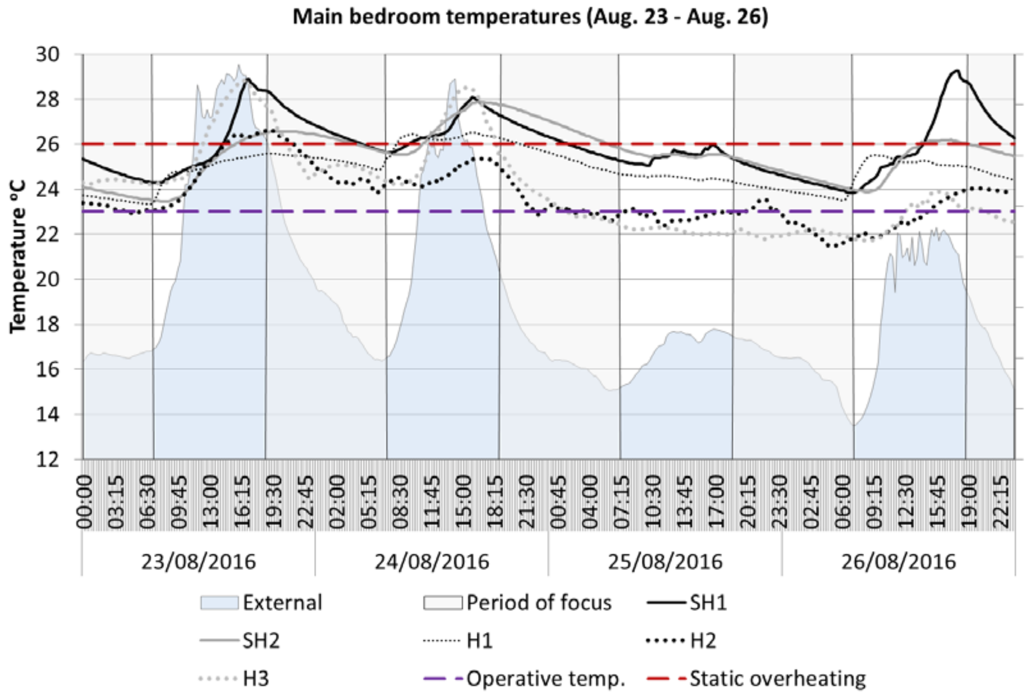

Figure 2. Occupied vs. unoccupied dwelling temperatures in bedroom 1

Orientation

Considering the orientation of the rooms, table 3 demonstrates the following. There is greater tendency to overheat in south, west and east facing rooms. Excluding the influence of occupants, it might be concluded that dwellings with E/W orientation (e.g. SH1) have a much greater tendency to overheat than N/S.

Different occupancy hours

Those most vulnerable to overheating, such as the elderly or sick, are more likely to occupy their homes during daytime, when the heat is most intense. Whereas in the preceding analysis, occupied hours are assumed to be generalized, the following explores a scenario where the dwellings are occupied full time. Figure 3 shows a side-by-side comparison of total hours and occupied hours (the hours assumed in the methodology above).

At first, it is expected that in most cases, total hours will show greater overheating than the occupied hours due to the higher daytime temperature and direct solar gain. This does appear to be true for a majority of the spaces, especially the 2nd bedroom in H2 and the 1st bedroom in the SH1. Interestingly however, bedroom 2 in H3 has a higher level of overheating during the generalized occupied hours as opposed to the total hours. The fact that this space is southwest orientated could help to explain this; that is, most of the overheating occurs in the late afternoon / evening hours, as the sun sets, closer to occupancy time of the bedroom. Also in reality, actual presence of people (H3 has most occupants) in the space can add to the internal heat gain of the room, thereby, increasing the actual measured temperature of the space during assumed occupancy hours.

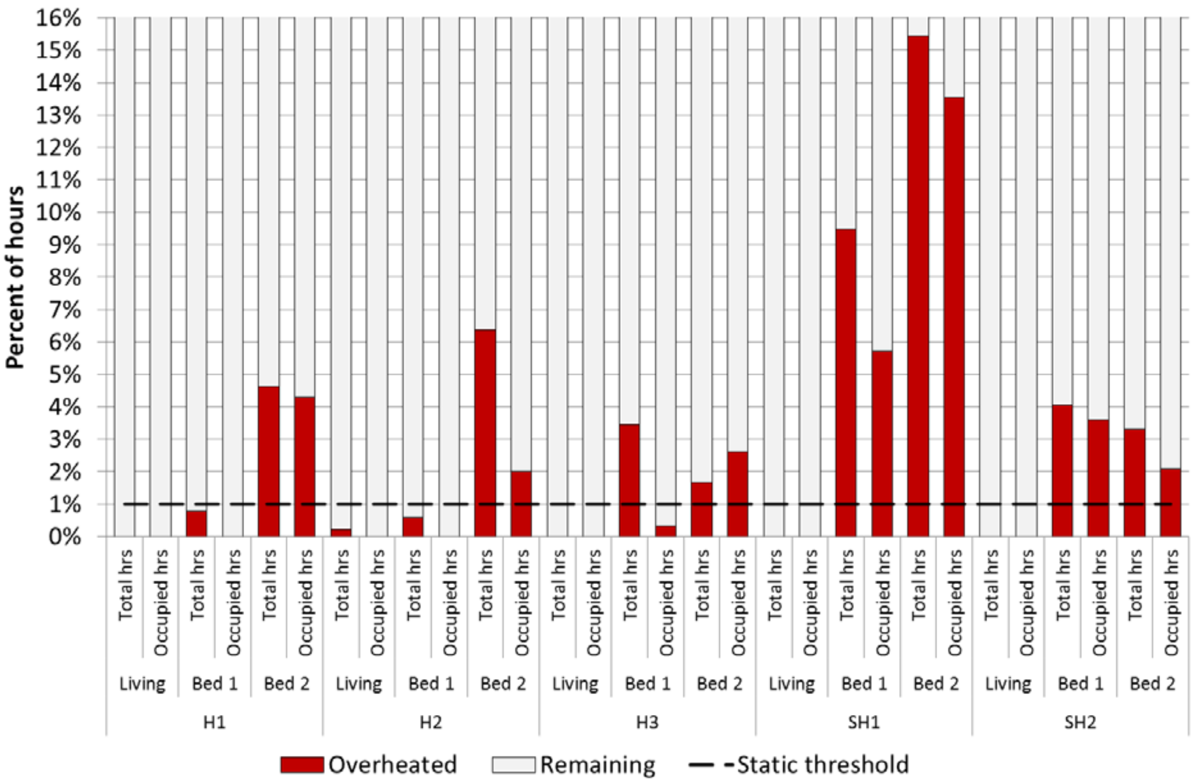

Figure **3**. Percent of hours overheated for all rooms

Concluding discussion

This study is based on data collected between August and November 2016 in five dwellings located in a new low-energy development in York, England. Analysis of the results showed that in general, overheating is prevalent in both occupied and un-occupied homes. Bedrooms, particularly those facing south, east or west, more specifically the upper levels of the dwellings, are more prone to overheating than living rooms. The living rooms in contrast, are large, open, and can be cross-ventilated and potentially well managed to avoid the risk of overheating. One contributing attribute is the open plan where the living room (or 'lounge') is shared with other spaces. In addition, in the two dwellings interviewed, the normal practice was to always leave the door open from the living space to the hall and stairs. This allows heat to move more freely and to not remain trapped in the living area. The movement of heat into the upper levels may also contribute to the higher propensity of overheating in the upper level rooms. It is also expected that this openness of all doors is prominent in the show-homes to give visitors a welcoming feeling.

SH1, an unoccupied dwelling, exhibited significant overheating results. The presence of occupancy appears to most obviously affect the overheating potential in bedrooms, where window ventilation is essential to alleviating or reducing overheating potential. No ventilation or fans were found among the interviewed occupants; however, the frequent use of windows in these dwellings has helped mitigate overheating to some degree in the monitored spaces. In most cases, where rooms are occupied all day, the overheating potential is higher. One exception to this is in southwest orientated bedrooms. These bedrooms tend to have overheating hours concentrated in the evening and at night.

It important to note that design has a heavy influence on overheating and given the findings, adaptive measures would definitely have their place in current new-build. Passive design strategies such as designed in shading and light coloured surfaces, etc., evaluated elsewhere (Porritt et al., 2012, Gupta and Gregg, 2013, McLeod et al., 2013), continually prove effective when tested in the literature. It is however, also vital to engage with occupant about managing heat during hot weather. Occupant behaviour is highly important when affecting the level of overheating. This is apparent in the assessment of both unoccupied homes and in second bedrooms of occupied homes where there is less or no occupant use of windows. Though SH1's temperature profile follows that of SH2, the internal temperatures are consistently 2°C higher in the bedrooms in the summer. The greater level of overheating in SH1 cannot be explained without further investigation into management of the space.

Acknowledgement

The research study is part of the Zero Plus research project, which has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No. 678407. The authors would also like to thank the developer and architect of the case study dwellings.

References

Armstrong, B. G., Chalabi, Z., Fenn, B., Hajat, S., Kovats, S., Milojevic, A. & Wilkinson, P. (2010). Association of mortality with high temperatures in a temperate climate: England and Wales. *Journal of epidemiology and community health,* 65(4)**,** pp.340-345.

Gupta, R. & Gregg, M. (2012). Using UK climate change projections to adapt existing English homes for a warming climate. *Building and Environment,* 55(September)**,** pp.20-42.

Gupta, R. & Gregg, M. (2013). Preventing the overheating of English suburban homes in a warming climate. *Building Research & Information,* 41(3)**,** pp.281-300.

Hajat, S., Vardoulakis, S., Heaviside, C. & Eggen, B. (2014). Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. *Journal of epidemiology and community health,* 68(7)**,** pp.641-648.

Humphreys, M. & Nicol, F. (2006). Environmental criteria for design. *In:* BRAHAM, D. (ed.) *Environmental Design: CIBSE guide A.* 7th ed. London: The Chartered Institution of Building Services Engineers.

Larsen, T. S. & Jensen, R. L. (2011). Comparison of measured and calculated values for the indoor environment in one of the first Danish passive houses. 12th Conference of International Building Performance Simulation Association, 14-16 November 2011 Sydney. pp.1414-1421.

Maivel, M., Kurnitski, J. & Kalamees, T. (2015). Field survey of overheating problems in Estonian apartment buildings. *Architectural Science Review,* 58(1)**,** pp.1-10.

Mcleod, R. S., Hopfe, C. J. & Kwan, A. (2013). An investigation into future performance and overheating risks in Passivhaus dwellings. *Building and Environment,* 70(December)**,** pp.189-209.

Nicol, F. & Spires, B. (2013). *The limits of thermal comfort: avoiding overheating in European buildings: CIBSE TM52: 2013,* London: The Chartered Institution of Building Services Engineers.

Porritt, S. M., Cropper, P. C., Shao, L. & Goodier, C. I. (2012). Ranking of interventions to reduce dwelling overheating during heat waves. *Energy and Buildings,* 5516-27.

Ruud, S. H., Lundin, L., Sandberg, M., Nielsen, J., Wahlström, A., Törnström, T. & Kovacs, P. (2005). Houses without a traditional heating system–results from two years of measurement. World Sustainable Building Conference, Tokyo, 27-29 September 2005 Tokyo. pp.1143-1150.

Sameni, S. M. T., Gaterell, M., Montazami, A. & Ahmed, A. (2015). Overheating investigation in UK social housing flats built to the Passivhaus standard. *Building and Environment,* 92(October)**,** pp.222-235.

Zch, Z. C. H. (no date). Overheating in Homes—An Introduction for Planners, Designers and Property Owners. Zero Carbon Hub.