Conference Proceedings of 5th International Conference on Countermeasures to Urban Heat Islands (IC2UHI) 2019
December 2-4, 2019, Hyderabad, India
https://doi.org/10.37285/bsp.ic2uhi.42

Assessing resilience to summertime overheating in modern low energy flats in UK

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ABSTRACT

This paper investigates the influence of physical and occupancy factors on the prevalence of summertime overheating in four new-built flats located in the same housing block in Southeast England. The dwellings were built to the same construction standards (building fabric thermal performance) and occupied by residents with similar economic status (high income). In-situ monitoring of indoor environment was carried out in the four flats using Hobo data loggers. Data on occupant behaviour were gathered using questionnaire surveys along with physical monitoring of opening-closing of windows. The paper focusses on the month of July as representative of the summer season.

The indoor temperature measurements in the summer revealed potential issues with overheating in the flats, especially those on the top floor. The maximum temperature in the southern exposed top-floor flats reached over 30°C, higher than the maximum outdoor temperature recorded over the same period. The lower level flats had more stable temperature and less overheating. Data on window opening showed that windows were regularly opened during the summer across the four flats, implying that occurrence of overheating could be due to lack of shading devices, as well as the high levels of insulation that prevented indoors to cool down in the night. Given the prevalence of summertime overheating found across the flats, it is necessary to carefully consider this risk during the design of homes, to avoid the growth of energy intensive and localized heat producing domestic air-conditioning in the future especially in a warming climate.

Introduction

The UK is legally committed to an 80% greenhouse gas emissions (GHG) reduction target for 2050 and to five-year carbon budgets in the interim set by the Committee on Climate Change (HM Government 2011). This has directed the need for new dwellings to be built with higher standards of insulation and greater air-tightness with managed ventilation. In addition, exploratory research projects and standards (Palmer et al. 2016, Gupta et al. 2015) are successfully driving the development of more advanced levels of fabric and system efficiency in housing beyond UK building regulations. Alongside this effort, there is growing evidence of overheating in UK homes (Lomas and Kane 2013, Beizaee, Lomas, and Firth 2013), particularly in newer homes built to satisfy more demanding standards of energy efficiency (ZCH no date). Though the term overheating is used to describe when higher temperatures make building

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occupants uncomfortable or heat stressed, it also has specific temperature thresholds. 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 several causes acting alone or together. These can include heat gain from high external temperatures (Haggag, Hassan, and Elmasry 2014), higher localised temperatures exacerbated by the urban heat island effect (Österreicher and Sattler 2018), 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 (Vellei et al. 2017), 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. 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 (CIBSE 2013).

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, Hopfe, and Kwan 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, Lomas and Kane 2013, Gupta, Gregg, and Bruce-Konuah 2017, Gupta and Gregg 2017, Roberts, Allinson, and Lomas 2018) in the UK and abroad, in Denmark (Larsen and Jensen 2011), Austria (Österreicher and Sattler 2018), Sweden (Ruud et al. 2005), and Estonia (Maivel, Kurnitski, and Kalamees 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^{o}C is problematic. To contribute to this body of knowledge, the objective of this study is to investigate the extent of overheating in four flats located in the same building in southeast England. The flats were completed and occupied in 2017 and were built to exceed the UK building regulations in fabric efficiency standards.

Methodology

Case study dwellings

The four case study flats are a part of a recent housing development built in southeast England; completed and occupied in 2017. The complex is composed of a mix of housing typologies – townhouses, cottages, apartments and penthouses - which surround a central courtyard lawn (figure 1). The flats are occupied by residents with similar economic status (high income) and have all been designed with the same performance standards: wall U-value: 0.16 W/m^{2}K; roof U-value: 0.10 W/m^{2}K; floor U-value: 0.16 W/m^{2}K; window U-value: 1.4 W/m^{2}K; air permeability: 4 m^3/h.m^2@50 Pa. External walls are composed of one layer of concrete blocks and one inner layer of insulation (mineral wool) and plaster. The external surface is either plastered or with brick claddings and windows are double glazed. The flats differ in size, orientation and location within the four storey buildings (table 1&2). All the flats are rated B in their Standard Assessment Procedure (SAP) documents, with primary energy ranging from 75.7 – 85.2 kWh/m^2/year.

Figure 1. View of the development from the courtyard.

Table 1. Case study physical characteristics

No.	Total floor area (TFA) (m^2)	Ratio of ext. surface area to TFA	Ratio of windows to TFA	SAP energy efficiency rating	Air perm. (m^3/h.m^2 @ 50 Pa)
N31	67	1.40	0.18	83 (B)	4.64
N15	72	0.39	0.10	84 (B)	3.03
N33	86	1.48	0.19	83 (B)	3.95
N06	95	1.43	0.15	84 (B)	3.31

Table 2. Case study occupancy details

No.	Beds / floor	Glazed orientation	Occ. no. and age range
N31	2 bed / 4th (top)	Facing adjoining building roof: NW (bedroom 2) – SW (living room & bedroom 1)	1: 46-55
N15	2 bed / 2nd	Facing street NW (all rooms)	2 (often 3): 16-25 and 26-35
N33	3 bed / 4th (top)	Facing street: NE (bedroom 1) - NW (bedroom 2 & 3) - SE (living room)	1: over 65
N06	3 bed / ground	Facing courtyard & sheltered: SE (all rooms)	1: 56-65

The tenant in flat N31 worked from home, using many office/electric appliances (monitors, desktop computer, laptops, amplifiers etc.) and was at home most of the time during both weekdays and weekends. In flats N15 there were two tenants plus one guest staying regularly on weekends. The tenant of flat N33 spent most of the time at home, but mostly in the living room/kitchen in which he would cook an relax occasionally with visitors. The tenant of

N06 lived alone but frequently had guests staying overnight (normally 1-3 days per week). Figure 2 shows the plans with installed environmental logger locations (explained later).

Figure 2. Plans and data logger locations.

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).

Table 3 lists the occupancy details for the flats. The greatest occupancy potential was used for the analysis in these models; i.e., a single pattern is applied to everyday, for example, though N15 works from home only 1-3 days per week, the days that the occupant works from home are used in the model to capture the worst-case potential.

Table 3. Case study occupancy details

No.	Living room	Bedroom 1	Bedroom 2	Occupancy details
N31	8:00 – 17:00 19:00 – 21:00	Not measured	Not measured	Works at home; away from home 5-10% of year: modelled as away 2 hours per day.
N15	8:00 – 17:00 19:00 – 21:00	22:00 – 7:00	22:00 – 7:00 (freq. guest)	1 works at home 1-3 days per week; away from home 5-10% of year: modelled as away 2 hours per day.
N33	8:00 – 21:00	22:00 – 7:00	Not measured	Most of the time at home; goes to gym on Wednesdays
N06	12:00 – 21:00	22:00 – 7:00	22:00 – 7:00 (freq. guest)	Works at home / out mornings and evenings on weekends

Performance evaluation

In-situ monitoring of indoor environment (air temperature and CO_2 levels at five-minute intervals) was carried out in the four flats using Hobo and Tinytag data loggers. Data loggers were placed in the rooms listed in table 3; figure 2 shows the plans and data logger locations. Data on occupant behaviour were gathered using questionnaire surveys along with physical monitoring of opening-closing of windows. Monitoring and survey data for the summer were gathered from 26 June – 26 July 2017 and BUS surveys where carried out at the end of May 2018. Window opening ratio (WOR) was calculated by multiplying the percentage of open (from 0 – 100%) by the number of seconds the window is open for every hour. This paper focusses on the month of July as representative of the summer season. A limitation of the study is the short period of monitored data as most overheating methods recommended assessing the period from 1 May – 30 September. The original purpose of this study was an annual energy consumption evaluation; however, some learnings can be taken from this regarding overheating in flats.

Results

The indoor temperature measurements in summer revealed overheating concerns in most of the flats, especially in the penthouses. Table 4 shows the overheating results for the flats. The only room to overheat using the adaptive method was the living room of N31. N31 also had the greatest maximum temperature reading (detailed later). Bedrooms generally tend to overheat more than living rooms though the living rooms were open to the kitchen, potentially providing more internal gains. Figure 3 shows the temperature ranges in the living rooms and bedrooms. The magnitude of static overheating can be seen here. The bedrooms show a much larger period (orange) where temperatures remained between the recommended temperature (23°C) and overheating (26°C) (CIBSE 2015).

Table 4. Overheating results *(OH = overheating)*

No.	Room	Window orientation / floor	Static method (occupied hours)	Static method (All hours)	Adaptive method (failed)
N31	Living room	Southwest / 4th floor	**34% - OH**	**21% - OH**	Criterion 2
N15	Living room	Northwest / 2nd floor	0%	0%	-
	Bedroom 1	Northwest / 2nd floor	**16% - OH**	**12% - OH**	-
	Bedroom 2	Northwest / 2nd floor	**23% - OH**	**14% - OH**	-
N33	Living room	Southeast / 4th floor	**11% - OH**	**9% - OH**	-
	Bedroom 1	Northeast / 4th floor	**33% - OH**	**30% - OH**	-
N06	Living room	Southeast / gr. floor	0%	0%	-
	Bedroom 1	Southeast / gr. floor	0%	**5% - OH**	-
	Bedroom 2	Southeast / gr. floor	0%	0.6%	-

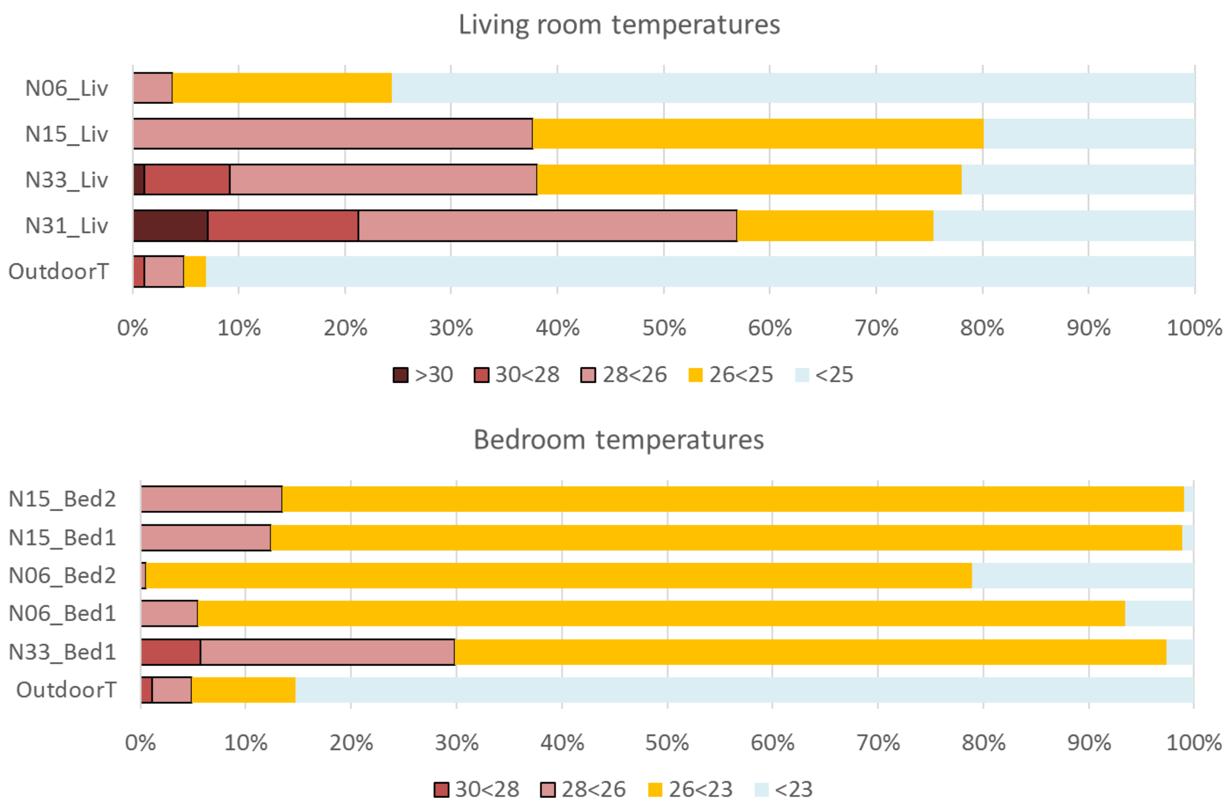

Figure 3. Temperature ranges in living rooms (top) an bedrooms (bottom).

The maximum temperature in the southern exposed top-floor flat, N31, reached up to 32°C, more than the maximum outdoor temperature recorded over the same period (30.3°C), while in N33 (northern exposure), indoor temperature reached up to 30.7°C. The mean indoor temperatures varied from 26.5°C in N33 and N31 to 23.9°C in N06, while the outdoor mean temperature was only 19.9°C. This means that indoor environments were generally warmer than outdoors in summer. As can be seen in figure 4, indoor temperatures were more stable in N15 and N06 and more variable in N31 and N33.

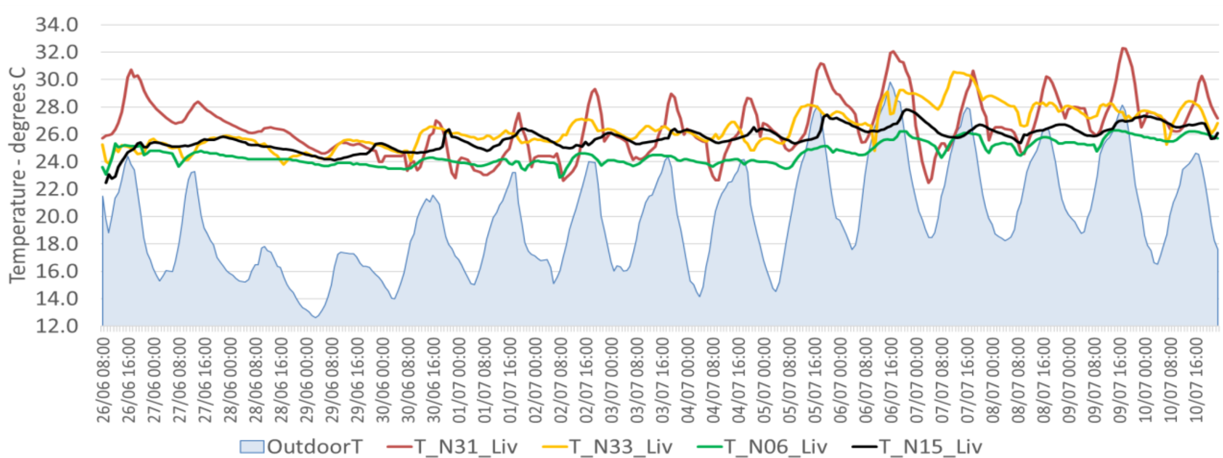

Figure 4. Living room temperatures during period of maximums (26 Jun – 10 Jul 2017).

Indoor air quality

Air quality in summer was good. As expected, CO_2 levels in summer were lower than in winter and spring, due to an average higher ventilation of the rooms in all the flats. The results showed a good air quality in all the flats. The mean CO_2 levels varied from 429 ppm in the living room of N33 to 725 ppm in the bedroom of the same flat. The 2000 ppm threshold was surpassed only once in one bedroom of flat N15.

Occupant survey

Building Use Studies (BUS) questionnaire showed that the occupants found the temperature and air in summer to be overall comfortable and satisfactory. These ratings were however at the higher end of the BUS benchmark for like-dwellings. When asked specifically about the range from too hot to too cold, occupants rated the dwellings as just a little on the hot side of neutral. This was again with in the benchmark range. Additional comments regarding comfort corroborated the findings with occupants of flat N06 showing higher levels of satisfaction with the indoor thermal environment. On the other hand, there were no comments from N31 and N33, and N15 concluded that the worst aspect about the flat is that it ‘gets very warm in the summer’.

Discussion

Three characteristics were reviewed for their impact on overheating potential in the flats. These were floor level, glazing orientation, and window opening behavior.

Temperature maximums and overheating are clearly most significant in N33 and N31. These flats are located on the top floor of the building. Though four case studies are not able to conclude statistical significance, the findings are in agreement with previous studies that found that roof-exposed rooms have statistically significantly higher mean daily temperatures than lower-floor rooms and that top-floor flats are at a higher overheating risk than lower-floor flats (Beizaee, Lomas, and Firth 2013, Vellei et al. 2017). Glazing orientation also appears to fit the hypothesis that south facing glazing leads to greater overheating; however, there are too few flats and many variables to consider. As examples, N33 and N31 have south facing glazing in their most overheated rooms; however, they are located on the top floor which may have greater influence. N06, located on the ground floor, demonstrates little to no overheating. N06 has south facing glazing but is facing garden courtyard and is in a corner of the building where the building is shading the glazing for much of the morning and late afternoon. Nonetheless, Vellei et al. (2017) found that south-facing rooms were not found to have statistically significantly different mean temperatures than north-facing rooms in their study.

Another variable to complicate matters is window opening behavior. Window opening appeared to have little to no influence on the internal temperatures of the flats. As examples, N33 had an average window opening ratio (WOR) of 761 and N31 = 0.18. Though the windows were used far more in N33 the correlation (r) between external and internal temperature were the same. The WOR in N15 was much higher at 1,116 but the external and internal temperature r = 0.37. Though data showed that windows were regularly opened during the summer across the four flats, it appears that the high levels of insulation prevented indoors from cooling down at night, due also in part to the lack of cross ventilation. High levels of direct solar radiation could be to blame which would suggest the need to for shading devices especially in the most exposed top floor flats. The lack of occupant comment of overheating could likely be attributed to the timing of the BUS survey. As the BUS surveys where carried out at the end of May 2018, this was almost a year after the environmental monitoring, long after the experience of the summer.

As can be seen in the image of the courtyard above, the site is surrounded by green space and light-colored surfaces, which though not measured, are expected to have moderated the microclimate and reduced the incident heat on the flats. Though the environmental surroundings of the flats are likely influential, a study of the impact of the UHI in London showed that the effects of built form and other dwelling characteristics appear to be more important determinants of variation in high indoor temperatures than the location of a dwelling within London's UHI (Oikonomou et al. 2012). The results of this study also show that design and occupancy factors are more influential than external temperature.

Conclusion

This study is based on data collected during the summer of 2017 in four flats located in a new low-energy development in southeast England. Analysis of the results showed that in general, overheating is prevalent in most flats, but most pronounced in upper level flats, particularly those with roof exposure. Bedrooms were more prone to overheating than living rooms; however, overheating depended more on the location of the flat in the building. The penthouses also showed much higher variability of indoor temperature compared to flats on lower levels. The mean indoor temperatures in summer varied from 26.5 °C to 23.9 °C, while the outdoor mean temperature was only 19.9 °C. The CO_2 levels were good throughout the summer in all the flats indicating enough ventilation for air quality. Windows were opened much more regularly in the summer than other times in the year.

Overheating occurrence was more prevalent using the static method as opposed to the adaptive method. This would suggest that the adaptive method is providing more leniency in high temperatures through the external temperature variation. Though not evaluated here, one aspect of this apparent leniency may stem from the fact that the adaptive method was designed for use in non-domestic environments.

Design has substantial influence on overheating. Passive design strategies such as integrated shading, ventilation, light-coloured surfaces as well as the use of green and blue spaces can help to avoid the risk of summertime overheating. Lack of such measures may encourage occupants to turn to air-conditioning for cooling as the climate warms.

Acknowledgments

We are grateful to Innovate UK for sponsoring the I-life research project. Thank you to the occupants of the flats for allowing us to study their homes for over a year. We are also grateful to Dr Agnese Salvati and Luka Oreskovic for their work in gathering the data used for this study.

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