Assessing the Current and Future Risk of Overheating in London's Care Homes: The Effect of Passive Ventilation

Ioanna Tsoulou[1], Nishesh Jain[1], Eleni Oikonomou[1], Giorgos Petrou[1], Alastair Howard[2], Rajat Gupta[2], Anna Mavrogianni[1], Ai Milojevic[3], Paul Wilkinson[3], Michael Davies[1]
[1]University College London (UCL), London, UK
[2]Oxford Brookes University, Oxford, UK
[3]London School of Hygiene and Tropical Medicine (LSHTM), London, UK

Abstract

The warming climate causes adverse effects on thermal comfort and health, especially for vulnerable older adults. This study assesses the current and future risk of summertime overheating in London's care homes and explores the potential of passive ventilation on reducing these risks. Analysis is based on temperature monitoring of two care settings and on thermal simulation models of future conditions with and without passive ventilation strategies. Results show high overheating exposures for both care homes, with temperatures averaging 31-35 ^{0}C by 2050. Passive ventilation can substantially reduce these exposures, but a successful approach depends on time of day, duration and window characteristics. Dynamic window opening based on lower outdoor temperatures and indoor temperature exceedance of 22 ^{0}C is the most beneficial approach for both settings now and in the future. The study demonstrates the effectiveness of affordable building adaptations for reducing heat stress in senior care homes.

Key Innovations

- Our research represents a novel method to evaluate heat-related risks to health in care settings under a representative set of climate change scenarios.
- The results of our thermal models add to evidence on the effect of passive ventilation in care homes with contrasting building characteristics.
- Our findings have important policy implications for the short-to-mid-term application of indoor ventilation strategies to protect older adults in care homes.

Practical Implications

Our work highlights the effectiveness of passive ventilation in reducing the risk of overheating and provides guidance for public health officials, care home providers and building code professionals who seek to transform indoor spaces through the use of inexpensive and easy-to-implement building adaptations.

Introduction

Climate change increases the likelihood of warmer summers and heat waves, which can result in indoor overheating with adverse effects on thermal comfort and human health (Pachauri et al., 2014). A wealth of literature has demonstrated higher morbidity and mortality rates due to heat stress (Arbuthnott and Hajat, 2017), which are becoming evident even in more temperate climates, such as the UK. During the extreme heat wave of summer 2003, the European death toll exceeded 70,000 out of which, 2,000 deaths were recorded in England and the Wales (Robine et al., 2008). More recently, the UK experienced national all-time high temperatures (Met Office, 2020), which resulted in 892 excess deaths for the 65+ age group during July and August 2019 heat wave episodes (PHE, 2019).

The World Health Organization (WHO) estimates that summer heat will increase appreciably between 2030 and 2050 (WHO, 2014), with recent projections suggesting rises in associated mortality of more than 200% in the UK by 2050 (Hajat et al., 2014). Older people and those who are physically frail are more vulnerable to heat, (Kovats and Hajat, 2008), which is especially important for countries with an ageing population, such as the UK (Office for National Statistics, 2015).

Seniors spend more than 85% of their time indoors (Hughes and Natarajan, 2019), therefore the role of buildings and the indoor environmental conditions they experience are critical during heat waves. Of special attention is housing for older people, such as care home settings - studies have shown that such environments may be more prone to overheating (Gupta et al., 2017).

To date, there is limited documentation of the real exposures to summertime overheating inside residential environments (Pathan et al., 2017) and even fewer studies assess current and future heat risks to older people and how these risks may be reduced by building adaptations (Kingsborough et al., 2017).

Therefore, the primary goal of this study is to investigate the short-to-mid-term (2050) risk of summertime overheating for older people living in two London's care homes with contrasting building characteristics. We further explore the potential of passive ventilation and window opening on reducing these risks, aiming to inform policy recommendations for the large-scale application of practical and easy-to-implement building interventions.

Methods

Our study of thermal environments focuses on an old and a modern care home in London, UK, using empirical observations and building thermal simulations. Indoor temperatures were obtained through continuous monitoring during summer 2019 and were used to calibrate thermal simulations (EnergyPlus V8.9 via the DesignBuilder Graphical User Interface) of current and future conditions with and without passive cooling measures, specifically ventilation through window operation.

Case Studies

The two care homes (C and A) that were recruited for this study differ in age, construction type, building typology and occupancy, as summarized below and in Table 1. Their locations within greater London are shown in Figure 1.

Care home C: located in an urban setting within central London, this is the "old" care home that is naturally ventilated and is composed of a south-facing 2-story building with a courtyard garden. It is heavy-weight and was constructed as a 14th century monastery that was renovated in 2004. All resident rooms (11 in total) are of single occupancy, south orientation, located on the 1st floor and have no window restrictors. The building is currently occupied by 8 residents.

Care home A: located in a suburban setting within west London but close to a dual carriageway, this is the "modern" care home that is naturally ventilated and is composed of a southeast facing 3-story building with parking and a small garden. It is medium-weight and was constructed in 1980 as a pub that was converted to a care home in 1993. Resident rooms (40 in total) are in their majority of single occupancy, southeast or northwest orientation and have 10 cm window restrictors. The building is currently occupied by 38 residents.

Figure 1: Locations of the two care homes (Google, n.d.).

Environmental Monitoring

After the care homes selection, data loggers were installed in the study settings to monitor outdoor and indoor temperatures. Specifically, one outdoor logger (Hobo MX2301) (Onset) was placed in each care home's garden, at a shaded location to avoid exposure to direct sunlight and precipitation. The outdoor logger's range is from -40 to 70 ^{0}C, with ±0.2 ^{0}C accuracy and 0.04 ^{0}C resolution. Indoors, loggers (Hobo UX100, iButton DS1922L) (Measurement Systems Ltd.; Onset) were located at one common space (1st floor dining room in C and 1st floor lounge in A) and at one 1st floor resident room within each care home, at approximately 0.5m height and away from windows and air drafts. The indoor loggers' ranges are from -20 to 70 ^{0}C, with ±0.21 ^{0}C accuracy and 0.024 ^{0}C resolution. All loggers reported at 5-min intervals during the summer of 2019. The final dataset covers from June 17 to September 10, 2019 at 24-h intervals.

As guidance for assessing indoor overheating, our data analysis relied on Public Health England's recommendation (PHE, 2015), according to which, temperatures should not exceed the threshold of 26 ^{0}C.

Table 1: Background characteristics of the two care homes.

	Care Home C	Care Home A
Neighborhood	Urban	Suburban
Gross area (m_2)	456.2 m_2	1574 m_2
Year built	1348 (2004 conversion/renovation)	1980s (1993 conversion/renovation)
Stories	2	3
Height	3.70 m	2.30 m
Occupancy/ capacity	8/11	38/40
Roof	Unoccupied pitched	Partly pitched/ partly flat
Ground floor	Solid, uninsulated	Solid, uninsulated
External wall	Stone built, uninsulated	Brick built, cavity wall insulation
Glazing	Single	Double
A/C availability	1 portable unit in the 1st floor dining room and 5 portable units available on demand	2 portable units in the 1st floor lounge
Other cooling measures	Operation of curtains and windows (restrictors not in use unless A/C on), use of dining room and courtyard	Operation of curtains and windows (10 cm restrictors at place), use of common spaces

Thermal Simulations

Following monitoring data collection, DesignBuilder V6 (DesignBuilder Software Ltd., 2019a), a graphical user interface for EnergyPlus V8.9 (DOE, 2019), was used to develop thermal simulation models for a whole summer (June 17 - September 10), for the two care homes, under two weather scenarios:

Current: (2019) weather files from the closest weather stations to the two case studies (Northolt and London Weather Centre) DesignBuilder Climate Analytics tool (DesignBuilder Software Ltd., 2019b), and

Future: based on Design Summer Year 1 (DSY1) 2050 high emissions scenario UKCP09 weather data from CIBSE (DEFRA, 2019).

The majority of the models' input assumptions relied on documentation of the care homes physical, technical and occupancy profiles through walk-throughs, observations and surveys that were undertaken at the same time of monitoring data collection. Building fabric-related input was taken from Reduced SAP (RdSAP) (DECC, 2017) for buildings with similar age and typology.

Lighting heat gain density was set at 12.7 W/m_2 in both settings and lights were considered to be on 6pm-11pm and proportional to floor area, based on guidance from CIBSE's design methodology for the assessment of residential overheating risk (TM59) (CIBSE, 2017). Regarding occupancy, resident rooms were assumed to be continuously occupied by one person, based on TM59 recommendations. For common spaces, average daily occupancy was set to 4 for C and 15 for A, based on observations of the two care homes. Lastly, regarding ventilation, window openable area was set to 50% for care home C (with no window restrictors) and 12.5% for care home A (due to the existence of 10cm window restrictors), while the percentage of open windows varied, depending on the simulation scenario (Table 2). The ventilation rates were calculated using wind and buoyancy-driven pressure, opening sizes and operation, crack sizes and inside vs outside air temperature control, using the EnergyPlus Airflow Network.

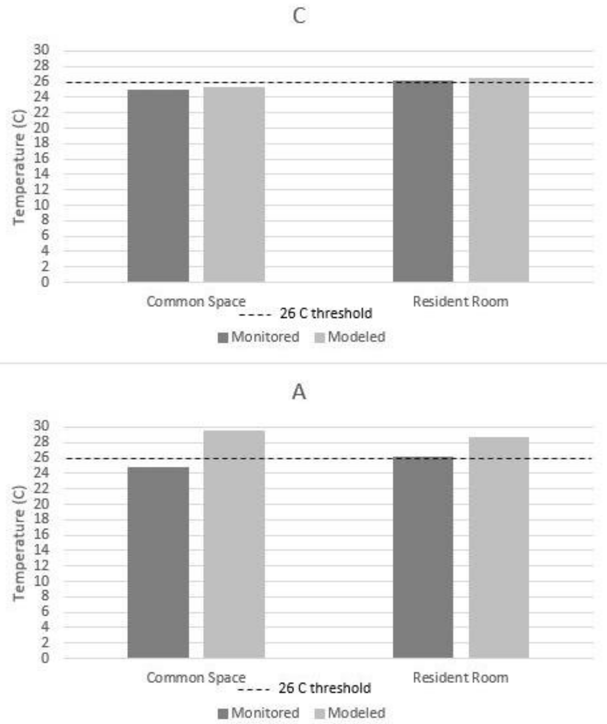

Figure 2: Monitored vs modelled (2019) average temperatures in common spaces and resident rooms of care homes C and A.

Simulation outputs from the baseline model (S0 of Table 2) were compared to the monitoring data for the study period of summer 2019. Average monitored vs modelled indoor temperatures from common spaces and resident rooms of each care setting are shown in Figure 2. Figure 3 further presents comparisons between measured and simulated data over the course of a 5-day heat wave period. Overall, results suggest that the two datasets are closely aligned for both care homes, with differences within an acceptable 2 ^{0}C range (Jain et al., 2020), and can therefore be used as a basis for further analysis of future temperatures.

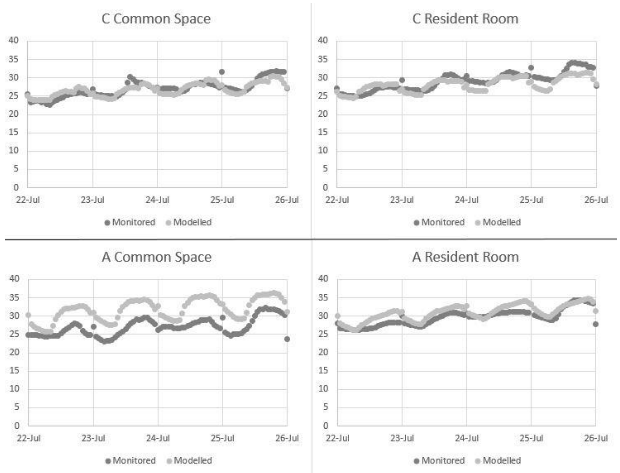

Figure 3: Hourly monitored and modelled temperatures in common spaces and resident rooms of care homes C and A during a 5-day heat wave period of summer 2019.

Specifically, within care home C, average temperature differences are 0.3 and 0.4 ^{0}C for common space and resident room zones respectively, which suggests that the two datasets are closely matched (Jain et al., 2020). In care home A, the resident room temperature difference is closer to 2.5 ^{0}C, which relates to the uncertainty of the baseline model assumption that windows were continuously closed (S0 of Table 2). Likewise, a higher discrepancy can be observed between the monitored and the modelled common space temperature, which is also because the baseline model did not consider the existence of two portable A/C units in this zone (Table 1), as this work focuses solely on the effectiveness of passive cooling strategies in reducing indoor temperatures.

Table 2: Building adaptation scenarios for thermal simulations based on passive ventilation.

ID	Category	Specifications
S0	Baseline	Windows: 100% closed
S1	Morning ventilation (7am-11am)	Windows: 83% closed
S2	Evening ventilation (7pm-9pm)	Windows: 92% closed
S3	Night ventilation (9pm-7am)	Windows: 58% closed
S4	Continuous ventilation	Windows: open when outdoor temperatures are lower than indoors, and indoor temperatures exceed 22 ^{0}C

After model validation, the care homes' baseline models were utilized to assess the future risk of overheating and to test the potential to reduce current (2019) and future (2050) overheating through a group of building adaptation scenarios related to passive ventilation, shown in Table 2. The simulation outputs produced hourly indoor temperatures for the same common spaces and resident rooms that were monitored, over the summer period (June 17 - September 10). The baseline model (S0) assumed 100% closed windows to capture more clearly the effect of ventilation in subsequent scenarios.

Results

Current Thermal Conditions and Overheating Risk

During summer 2019, monitored indoor temperatures averaged 24.9 (common space) and 26.1 ^{0}C (resident room) in care home C, and 24.7 (common space) and 26.1 ^{0}C (resident room) in care home A. As shown in Figure 4 and Table 3, more than 16% of measurements in common spaces and more than 44% in resident rooms exceeded PHE's threshold of 26 ^{0}C. Highest peaks were reached on July 25, where data loggers recorded 31.7, 34.1, 32.3 and 34.3 ^{0}C in common spaces and resident rooms of care homes C and A respectively. For the whole monitoring period, while indoor temperature series followed the outdoor trend, common spaces and bedrooms were consistently 7-8 ^{0}C warmer than outdoors in both settings, likely due to limited ventilation through windows and confounded by internal gains.

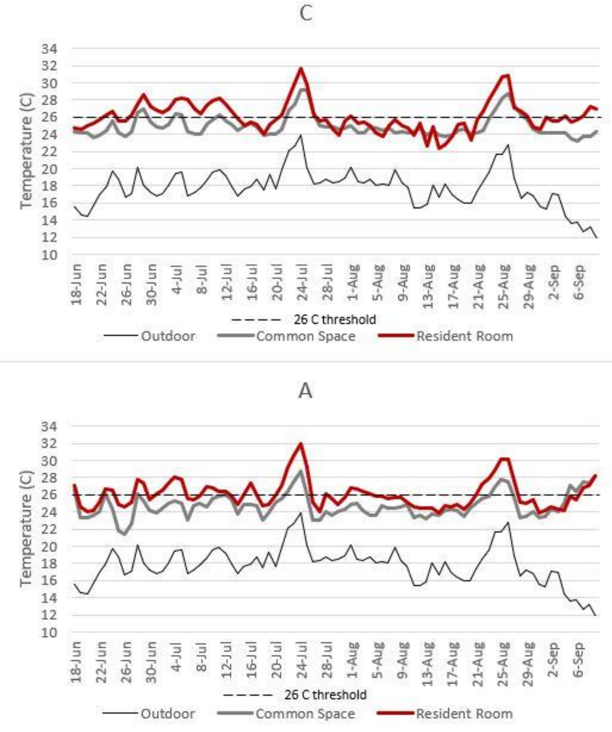

Figure 4: Monitored daily average temperatures in common spaces and resident rooms of care homes C and A during summer 2019.

Overall, temperatures from both the old (C) and the modern care home (A) remained within similar ranges, while no significant variations were observed between day and night times (Table 3 and Figure 1 of Appendix). Yet, resident rooms were continuously warmer than common spaces in both homes (Figure 4), which may relate to the use of portable A/C units in the latter (Table 1), and/or the absence of additional cooling measures in the resident rooms, such as opening windows. From all monitored spaces, the highest temperature and range was observed in the resident room of the old care home (C), which was expected given differences in building characteristics (e.g. single glazed windows).

Future Risk of Overheating

Thermal simulation analysis of the two care homes showed a much higher risk of overheating in 2050, (high emissions scenario). In the baseline model S0 of Table 2 (no passive cooling measures added), almost 100% of projected temperature measurements fail to meet PHE's threshold of 26 ^{0}C, as shown in Figure 5 and Table 3, while average temperatures in common spaces and resident rooms are expected to increase by 6-10 ^{0}C compared to the monitored data from 2019. For comparison, outdoor temperatures in 2050 (high emissions scenario) are expected to increase by 4 ^{0}C on average, compared to 2019, as shown in Figure 2 of Appendix.

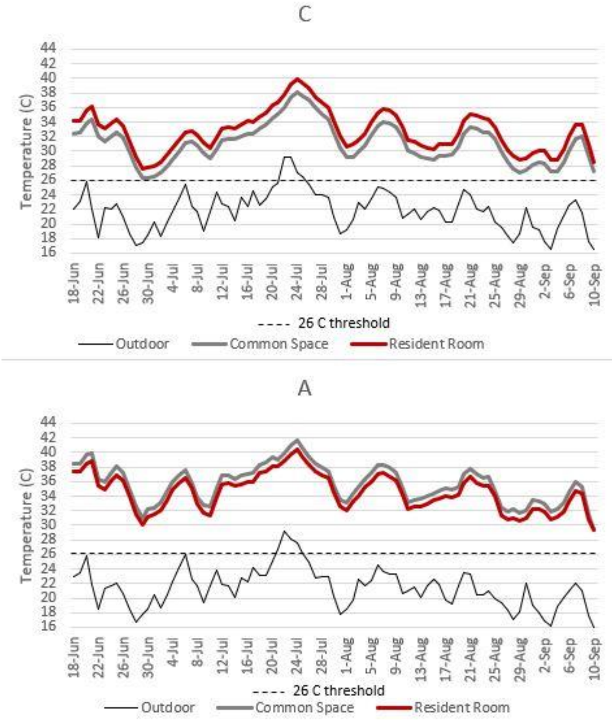

Figure 5: Modelled daily average temperatures in common spaces and resident rooms of care homes C and A during summer 2050.

Table 3 further shows small variations between day and night temperatures (1-2 ^{0}C higher during the day), however, the newer care home (A) is expected to be much warmer than the older (C), with typical temperatures ranging between 32-36 ^{0}C compared to 28-35 ^{0}C in the former. Lastly, resident rooms and common spaces are expected to be similarly warm in both care homes, with average temperature differences of 1 ^{0}C (Figure 5).

Passive Ventilation: Effect on Thermal Conditions

Figures 6-9 and Table 4 present the effect of four building adaptation scenarios (see Table 2) on the baseline models S0 of the two care settings, based on simulated temperature ranges experienced in common spaces and resident rooms. Overall, results for current (2019) and future (2050) conditions suggest that if no cooling measures are implemented, residents of both care settings will be under severe risk of overheating in the future, especially those living in the newer care home (A). To some extent, this may relate to the existence of window restrictors in A, which limits the influence of passive ventilation. They further indicate that within C, resident rooms will remain consistently warmer than common spaces under all scenarios (0.3-1.6 ^{0}C higher), while the opposite can be observed for care home A (0.6-1.1 ^{0}C higher in common spaces).

Table 3: Descriptive statistics of monitored and modelled temperatures in care homes C and A during summers 2019 and 2050.

Monitored Temperatures in ^{0}C (2019)					
		C		**A**	
		Common Space	Resident Room	Common Space	Resident Room
All	**Average**	24.94	26.08	24.72	26.07
	Min	22.47	20.42	17.89	22.40
	Max	31.77	34.08	32.26	34.34
	>26 ^{0}C	16%	46%	22%	44%
Day	**Average**	24.99	26.24	25.00	26.07
	Min	22.47	20.42	18.06	22.40
	Max	31.77	34.08	32.26	34.34
	>26 ^{0}C	17%	50%	26%	43%
Night	**Average**	24.86	25.80	24.27	26.07
	Min	22.73	21.04	17.89	22.97
	Max	31.65	32.88	30.86	33.71
	>26 ^{0}C	15%	38%	15%	44%
Modelled Temperatures in ^{0}C (2050) Baseline Model (S0)					
		C		**A**	
		Common Space	Resident Room	Common Space	Resident Room
All	**Average**	31.18	32.80	35.70	34.64
	Min	24.56	25.59	28.06	28.08
	Max	39.99	41.31	44.06	42.48
	>26 ^{0}C	97%	100%	100%	100%
Day	**Average**	31.62	33.43	36.52	34.88
	Min	24.56	26.03	28.06	28.18
	Max	39.99	41.31	44.06	42.43
	>26 ^{0}C	98%	100%	100%	100%
Night	**Average**	30.44	31.77	34.35	34.23
	Min	24.58	25.59	28.10	28.08
	Max	39.24	41.13	43.05	42.48
	>26 ^{0}C	95%	99%	100%	100%

Among the four simulation scenarios (S1=morning, S2=evening, S3=night and S4=continuous ventilation), continuous ventilation with windows open when outdoor temperatures are lower than indoors, and indoor temperatures exceed 22 ^{0}C (S4) has the highest impact on reducing the temperature averages and ranges of all spaces within both care homes, now and in the future. Under S4, more than 95% of modelled temperatures in care home C meet the 26 ^{0}C criterion for 2019 and more than 70% for 2050. Likewise, in care home A, more than 80% of measurements are less than 26 ^{0}C for 2019. However, a much lower percentage (27-35%) can be observed for 2050, which was expected given the 6-10 ^{0}C increase in indoor temperatures shown in Figure 5.

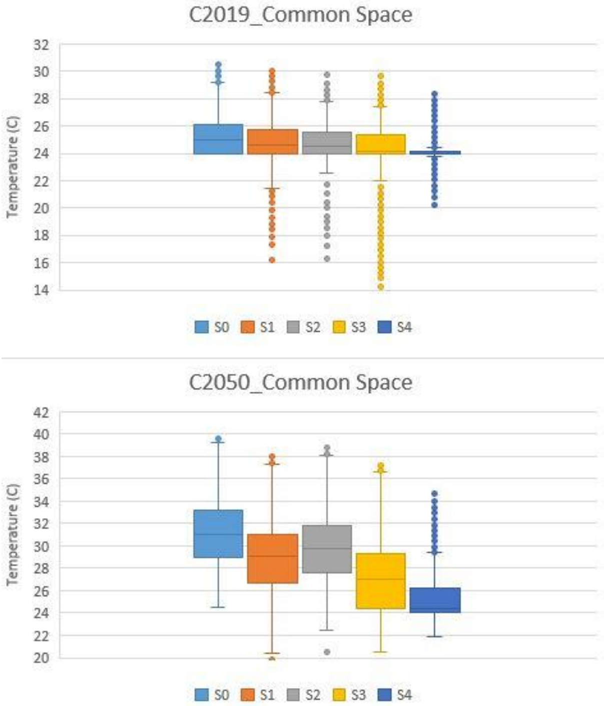

Figure 6: Modelled temperature ranges in common space of care home C under 4 ventilation scenarios during summers 2019 and 2050.

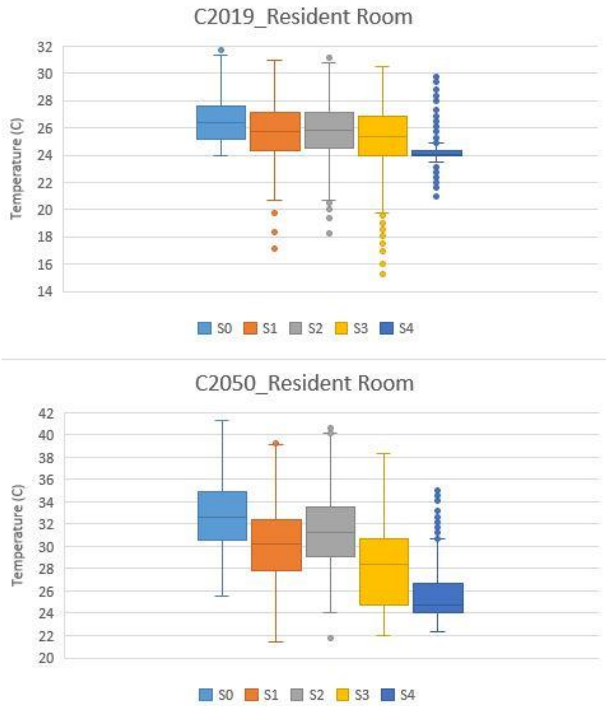

Figure 7: Modelled temperature ranges in resident room of care home C under 4 ventilation scenarios during summers 2019 and 2050.

The next most impactful building adaptation approach appears to be night ventilation (S3), which aligns with previous studies (see Oikonomou et al., 2020). S3 has a particularly notable effect on the future (2050) indoor temperatures within care home C, with a reduction on average temperatures of 5.9 (common spaces) and 7.2 ^{0}C (resident rooms) compared to S0. The effect on average temperatures within A is equally strong (5.6-7.5 ^{0}C reduction compared to S0), for both 2019 and 2050, however, the interquartile range is wider with lower minimum temperatures compared to S4. Yet, while night ventilation is more meaningful for resident rooms than common spaces, it is more intuitive and easier to implement compared to S4, which requires a more dynamic ventilation approach based on outdoor temperatures.

Table 4: Descriptive statistics of modelled temperatures in care homes C and A under 4 ventilation scenarios during summers 2019 and 2050.

Modelled Temperatures in ^{0}C (Average & *Min-Max*) Ventilation Scenarios S1-S4				
C				
	2019		2050	
	Common Space	Resident Room	Common Space	Resident Room
S1	24.94	25.84	28.90	30.08
	(16.15-30.02)	*(17.15-30.99)*	*(19.84-38.03)*	*(21.46-39.24)*
<26 ^{0}C	80%	54%	19%	15%
S2	24.85	25.92	29.87	31.39
	(16.28-29.83)	*(18.24-31.37)*	*(20.46-39.16)*	*(21.80-40.72)*
<26 ^{0}C	85%	53%	9%	5%
S3	24.34	25.41	27.26	28.24
	(14.26-29.64)	*(15.28-30.51)*	(20.49-37.22)	(22.00-38.28)
<26 ^{0}C	86%	58%	41%	34%
S4	23.88	24.18	25.32	25.64
	(20.20-28.30)	*(21.00-29.82)*	*(21.90-34.68)*	*(22.32-35.05)*
<26 ^{0}C	98%	97%	74%	70%
A				
	2019		2050	
	Common Space	Resident Room	Common Space	Resident Room
S1	27.33	26.40	33.48	32.43
	(16.25-34.85)	(16.56-33.15)	*(24.26-42.37)*	*(24.02-40.92)*
<26 ^{0}C	34%	43%	1%	1%
S2	27.63	26.79	34.44	33.37
	(17.79-35.32)	*(17.45-33.27)*	*(26.88-43.64)*	*(26.86-41.34)*
<26 ^{0}C	34%	38%	0%	0%
S3	24.07	23.03	30.85	29.87
	(15.96-32.86)	*(15.61-31.10)*	*(21.81-41.21)*	*(22.24-39.42)*
<26 ^{0}C	60%	82%	14%	13%
S4	23.60	22.98	28.24	27.38
	(20.94-31.56)	*(20.97-29.75)*	*(21.88-38.89)*	*(21.85-37.43)*
<26 ^{0}C	81%	92%	27%	35%

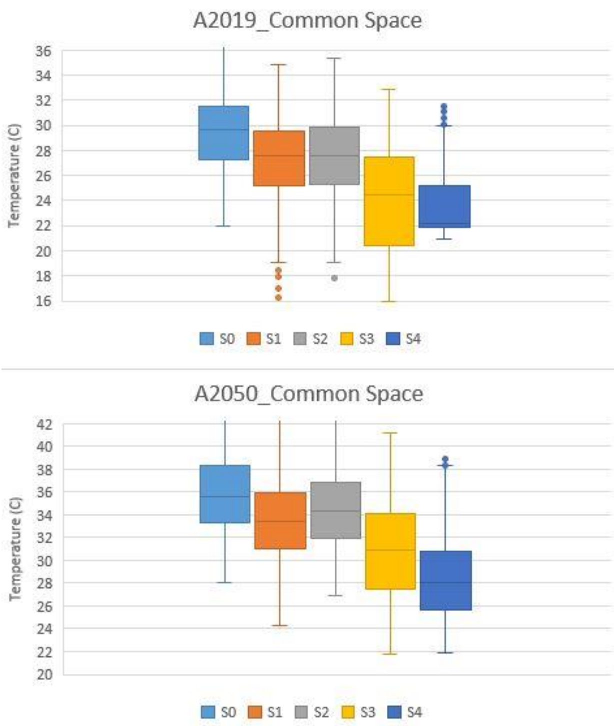

Figure 8: Modelled temperature ranges in common space of care home A under 4 ventilation scenarios during summers 2019 and 2050.

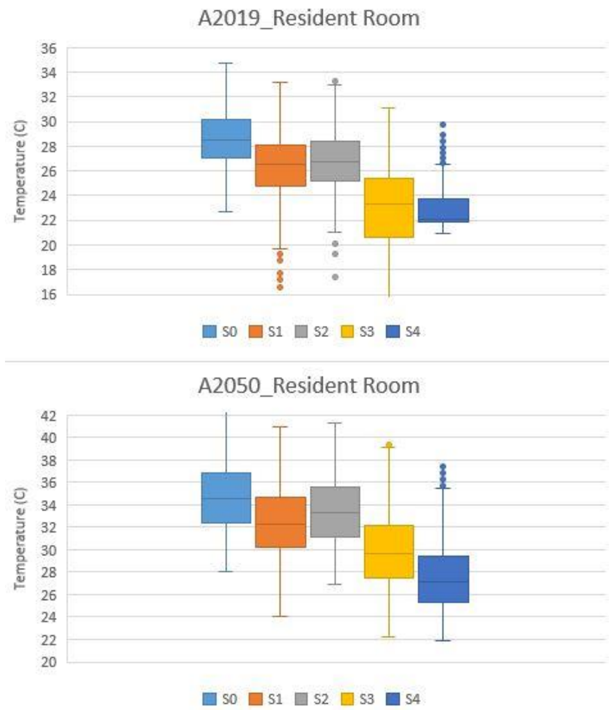

Figure 9: Modelled temperature ranges in resident room of care home A under 4 ventilation scenarios during summers 2019 and 2050.

The remaining scenarios related to morning (S1) and evening (S2) ventilation have an overall smaller, yet meaningful impact on indoor temperatures compared to S3 and S4. Temperatures from these two approaches are closely aligned, but morning ventilation is somewhat more beneficial than S2, with an impact range of 2.1-2.7

^{0}C that is more evident in the modern care home (A). Given their easy no-cost implementation, these ventilation strategies could still be proven useful for lowering overheating exposures, especially if combined together.

In summary, results from thermal simulation models have shown that the risk of overheating in both care homes and for both current and future climates can be highly reduced through passive ventilation, but an effective strategy is tied to individual building characteristics, especially the type of windows, as well as the time of day and duration of window opening. The strong effect of the last scenario S4 on indoor temperatures suggests that a more dynamic ventilation approach may be preferred over static approaches for improved thermal conditions.

Conclusion

This paper examined the indoor thermal conditions and exposures to summertime overheating experienced by older people in care homes and explored the potential of passive ventilation in mitigating these exposures in the near future. The analysis of monitoring data from summer 2019 showed that almost half of indoor temperature measurements exceeded the threshold of 26 ^{0}C. Findings from thermal simulation models suggested that the risk of overheating will likely be much higher by 2050 if no cooling measures are implemented.

Regarding the potential of passive ventilation to mitigate indoor heat, we found that it can substantially alter exposures, but an effective approach should consider time of day and duration of window opening, as well as window characteristics. Among the different strategies examined in this work, results showed that morning (S1), evening (S2) or night (S3) ventilation could all reduce current temperatures below 26 ^{0}C in a care home with no window restrictors. Yet, for future overheating reduction, it is best if they are used alongside additional passive measures, such as external shading and the application of high albedo materials, as indicated by Oikonomou et al. (2020). Nevertheless, this finding is important, since it confirms the value of manual window opening as an affordable and intuitive means to increase thermal comfort inside residential environments.

This study further illustrated that regardless of weather conditions and individual building characteristics, a very impactful measure to reduce overheating now and in the future is a more dynamic approach that depends on window opening when outdoor temperatures are lower than indoors, and indoor temperatures exceed 22 ^{0}C (S4). This finding suggests that while passive ventilation should be part of building adaptations in response to the future climate, a more strategic approach is required that will consider increased duration of window opening at certain times of day, coupled with building alterations such as removal of window restrictors. It further indicates the need of mechanical control for the optimal operation of windows.

As summarized above, our study has important implications for the protection of older adults from summertime overheating and the adaptation of old and modern care homes in temperate climates, since it identifies effective ways to shield indoor environments using inexpensive and readily available solutions. We reserve for future work a more detailed investigation of variations in indoor temperatures and associated passive ventilation strategies within care homes, through capturing the effects of additional building characteristics (e.g. floor number, orientation and window size) and occupant behaviours. Coupled with perspectives from public health officials, care home practitioners and stakeholders involved in built-environment preparedness for vulnerable groups, our research will inform public health sector plans for mitigating heat risks in care homes. It will also be relevant to building standards and guidelines with respect to the effect of low-cost and low-energy building adaptations in reducing the risk of overheating.

Acknowledgements

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Appendix

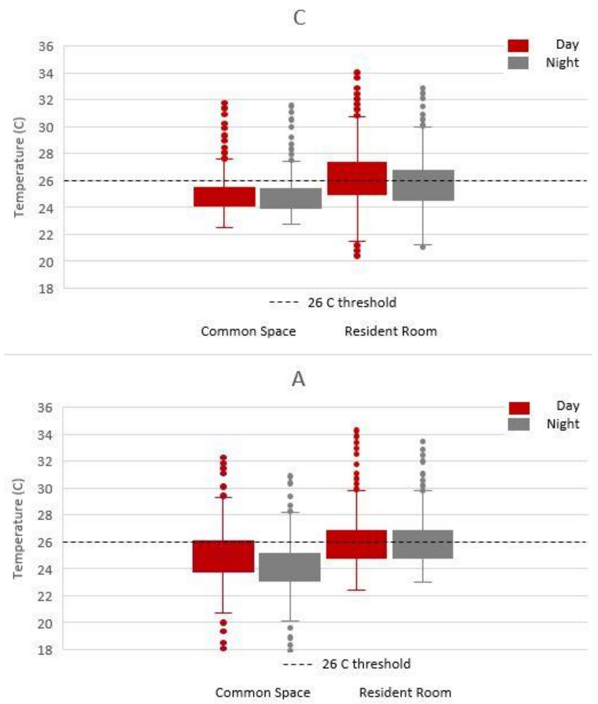

Figure 1: Monitored temperature ranges by day and night in care homes C and A during summer 2019.

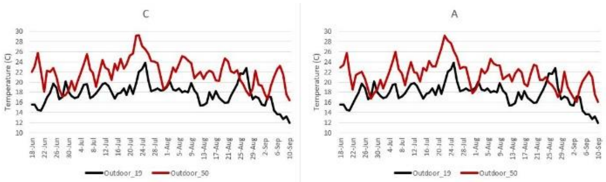

Figure 2: Daily average temperatures in outdoor locations of care homes C and A during summers 2019 and 2050.