Passive Strategies to Improve Thermal Conditions in a Care Home in London, UK

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ABSTRACT

This work assesses the current and future risk of summer thermal discomfort of older adults in a refurbished care home in London, UK. It further explores the potential of passive adaptations to improve indoor environmental conditions. Temperature and relative humidity data from continuous monitoring during summer 2019 were used to calibrate a building performance simulation model of the care home. Simulation outputs from two bedrooms and two lounges under the current (2019) and future climate (2080s with 90th percentile probability, high-emissions scenario under the UK Climate Projections 2009) were analyzed to evaluate the risk of indoor overheating and humidity discomfort, and to test the effectiveness of adaptation scenarios related to window operation and external shading. Results showed a high risk of exposure to high indoor temperature and low humidity under the current climate, which are expected to worsen in the future. Regarding the effect of passive adaptations, it was found that the highest potential decline in overheating and dry air incidence could be achieved through a combination of secured window opening at night and closing of external shutters during the day; yet this was compromised by an increased risk of humid air. Results further indicated that these strategies are not adequate under a future high-emissions climate scenario, which suggests that care homes need to combine passive and active ventilation to maintain indoor environmental comfort and reduce anticipated cooling demand.

INTRODUCTION

The continuous rise in ambient temperatures due to climate change is a global concern. Global warming from anthropogenic emissions is expected to be 1.5°C (2.7 °F) above the pre-industrial era by 2030 to 2052 (Masson-Delmotte et al. 2018) with more frequent, intense, and long-lasting heat waves in the next half of the century (Meehl and Tebaldi 2004). Excessive heat has been linked to several health risks and mortality (Pörtner, et al. 2022). Although everybody can be affected, a plethora of epidemiological studies suggest that older people are more susceptible to heat-health risks (Kaltsatou, Kenny and Flouris 2018). For example, England set a record of 2,556 total cumulative all-cause excess mortality on heatwave days during the summer of 2020 with 88% of them among the 65+ years group (PHE 2020). This is especially concerning for countries like the UK, where about 25% of the population will soon be over the age of 65 (ONS 2021), which in turn suggests a focus on settings such as aged care homes.

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Recent monitoring studies found that care homes across England are overheating even during relatively mild summers. Gupta, et al. (2021) revealed that bedrooms and lounges of two care homes in London exceeded the recommended limit by Public Health England of 26 °C (78.8 °F) (PHE, 2015). In the first Passivhaus care home in England, common rooms and bedrooms were found to overheat in mid-season and summer (Guerra-Santin, et al. 2021). It could be due to lack of cooling strategies and turning on the heater intentionally by the residents for their own comfort.

To cope with heat stress and keep indoor temperatures within acceptable limits, PHE (2015) advises the public to take adaptive actions, such as drinking of water or cold drinks, taking showers, and keeping the environment cool through window opening and applying internal and external shadings. Shading of windows through shutters or curtains and operating windows are among the actions that have been found effective in reducing indoor overheating in several simulation studies on dwellings in London (Mavrogianni, et al. 2014) and in care homes in Yorkshire (Gupta, Barnfield, et al. 2016) and in London (Oikonomou, Mavrogianni, et al. 2020).

When evaluating indoor thermal conditions, studies should also consider relative humidity (RH) alongside temperature. Sterling, Arundel and Sterling (1985) recommend maintaining RH between 40% to 60% for human comfort and to minimize adverse health effects from infectious microorganisms. High RH (>70%) prevents the body from releasing heat through the evaporation of sweat on the skin in a hot environment (Sobolewski, et al. 2021). Both low and high RH can cause irritation in the eyes and nose and subsequently increase the susceptibility to infection transmission and survival of microbes inside buildings (Wolkoff 2018). Infection outbreaks are frequently reported in UK care homes (Curran 2017), especially since the outbreak of the COVID-19 pandemic, where a devastating number of infection and transmission of COVID-19 led to care home deaths (Care Quality Commission 2021). Maintaining appropriate RH levels is, therefore, critical in care homes.

Some studies are already considering humidity alongside temperature for evaluating indoor thermal conditions. In Yorkshire, UK, a bedroom was found to overheat during occupied hours with slight incidence of low RH (<40%) (Gupta et al., 2016). In two care homes in London, low RH (<40%) was far more common than high RH (>60%) in bedrooms and lounges (Gupta et al., 2021). Outside the UK, Tsoulou et al. (2020) included indoor RH as part of thermal comfort evaluation of senior low-income residents in New Jersey, USA, and found that a high percentage of them complained regarding extreme humidity. They further found that the indoor heat index (combined measurements of air temperature and RH) had a significant effect on the residents' behaviors, particularly the opening of windows. Various studies have quantified the effect of adaptations such as window opening and closing of shutters on thermal comfort of care homes (see Gupta, Barnfield, et al. 2016 and Oikonomou, Mavrogianni, et al. 2020), however, they only focused on temperature. In response to the above, the aim of the present study is two-fold: (a) to investigate the thermal and relative humidity conditions of a care home in London, UK under the current and future climate, and (b) to further explore scenarios related to passive adaptation strategies, namely window opening and external shading, to understand whether they decrease the risks of overheating and humidity discomfort.

MATERIALS AND METHODS

The overview of the methodology is illustrated in the process flow diagram shown in Figure 1. Initially, a building performance simulation model of the care home under study was created and simulated in the summertime of 2019, when monitoring took place. Then, overheating and humidity discomfort risks of the final baseline model were assessed under current and future weather conditions. The simulation results were assessed based on selected overheating and RH thresholds. Last, adaptation scenarios related to window operation and external shading were developed and simulated based on the baseline model and were ranked based on effectiveness in improving indoor thermal conditions.

Case Study

The case study care home is situated in suburban London and was a pub for more than a decade before it was converted to a care home in 1993. It has three stories and is categorized as medium-weight with brick-built walls and ventilated naturally through windows (including some windows in the roof). The facades are largely unshaded; the front side is facing southeast towards a parking lot while the rear is facing northwest with views to a garden. There are 40 bedrooms in total mostly with single beds.

Two bedrooms and two lounges from the care home are selected to examine the impact of adaptations on different-floor rooms with different occupancy levels and profiles. Specifically, a middle bedroom and a lounge from the ground floor (B0 and L0, respectively), as well as a middle bedroom and a lounge from the first floor (B1 and L1 respectively) are selected.

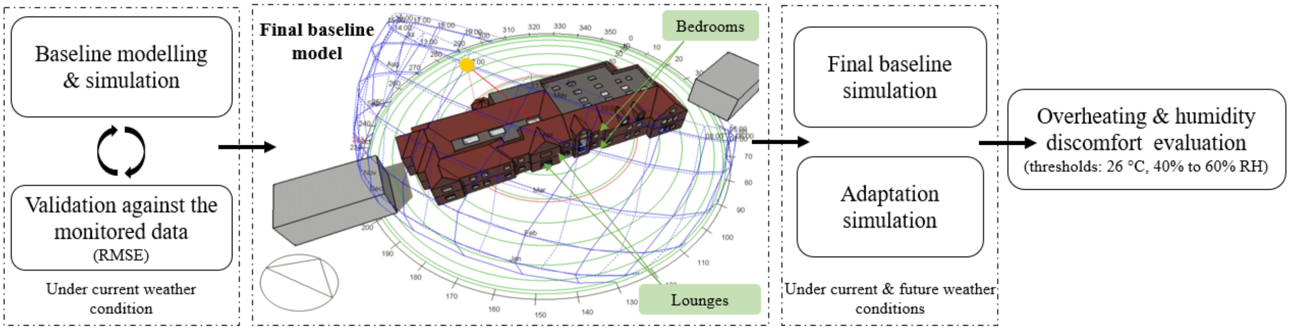

Figure 1 Summary of process flow.

Monitoring Data

The research team installed data loggers to record indoor dry-bulb temperature (T_m) and RH in first floor bedroom (B1) and lounge (L1) of the care home (same rooms with the monitored) at 5-min intervals from 17th of June to 12th of September 2019. The loggers were located at approximately 0.5 meter (1.64 feet) height and away from windows, air drafts, and other sources of heat such as radiators and television screens. The data loggers can record temperatures within the range from -20 to 70 °C (-4 to 158 °F) with ±0.21 °C (0.38 °F) accuracy and 0.024 °C (0.043 °F) resolution.

Baseline Modeling

Modeling and simulations were performed in DesignBuilder Software (2021), a Graphical User Interface for EnergyPlus software V9.4 (DOE 2020), validated as per ASHRAE 140 Standard. Modeling inputs related to the building geometry, fabric parameters, and internal gains were based on the monitoring team's observations, shown in Table 1. The occupancy profiles were based on CIBSE TM59 (CIBSE 2017), a widely used domestic overheating assessment guidance document in the UK. To quantify the impact of window opening and use of external shading, the baseline model included no external and internal shutters and windows closed. These assumptions also align with the behavior of residents in care homes, as reported by Gupta et al. (2021).

The baseline model was run in the summertime (17th of June to 12th of September) using 2019 weather data from Heathrow, London, taken from Climate Analytics (DesignBuilder Software Ltd., 2019). This weather file was selected to align with the monitoring data and to represent current weather conditions. According to the UK meteorological office (Met Office 2019), early summer (June) was generally wet, while the end of the summer period (August) was relatively hot and dry in London. In comparison with the UK average temperature and RH, the summer mean temperature of the 2019 weather file of Heathrow was above the recorded temperature by Met Office data (15.6 °C or 60 °F) by 2.1 °C (3.8 °F), while the RH mean was 9% below the Met Office (80.1%).

Table 1. Summary of initial model parameters and configurations.

	Modeling parameters	Description	Values
1	**Build form and Fabric**		
	Roof	partly pitched/partly flat	0.565 W/m^2-K (0.100 BTU/hr/ft^2/R)
	Level Height		2.3 meters (7.5 feet)
	Airtightness		0.7 ac/h at 50 kPa (7.25 psi)
	Exterior wall	Brick built, cavity wall insulation	0.418 W/m^2-K (0.074 BTU/hr/ft^2/R)
	Internal partitions	Plasterboard	1.64 W/m^2-K (0.289 BTU/hr/ft^2/R)
	Ground floor	Solid, uninsulated	1.22 W/m^2-K (0.215 BTU/hr/ft^2/R)
	Internal floor	uninsulated, suspended wooden	1.772 W/m^2-K (0.312 BTU/hr/ft^2/R)

		construction	
	Window	double glazing	0.7 SHGC, 3.094 W/m^2-K (0.545 BTU/hr/ft^2/R)
		Openable area	12.50% (due to window restrictors)
2	**Occupancy, activity, and load***		
	Number of occupants	Lounges (0900 - 1400) / (1400 - 2200)*	15/11
		Bedrooms (24 hours)*	1
	Metabolic rate	per person	130 W (443 BTU/hr)
	Natural Ventilation	None (Windows closed)	Whole day
	Mechanical Ventilation	Lounge	off
		Bedroom (heater), 2400 - 0900	0.5 (turned "On")
	Lighting	On (1800 - 2300)*	12.7 W/m^2 (4.026 BTU/hr/ft^2)
	Miscellaneous	Lounge equipment gain*	450 W (1535 BTU/hr)
		Bedroom equipment gain	80 W (273 BTU/hr)
*Time duration was based on CIBSE TM59 for domestic overheating assessments.			

Calibration

Currently, there are no standards or formal guidelines for acceptable air temperature calibration (Jain, et al. 2021). To address the errors, Root Mean Square Errors (RMSE, Equation 1) between the simulated indoor air temperatures (T_s) and the monitored T_m of the first-floor bedroom and lounge were calculated for the total number of observations (n) from the 3rd week of June to the 2nd week of September. Roberti, Oberegger and Gasparella (2015) applied this method to see the concentration of errors and understand their source. A maximum RMSE of 1.5 °C (2.7 °F) was further suggested by Jain, et al. (2021) to compare simulated versus actual data.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(T_m - T_s)^2}{n}} \qquad (1)$$

The RMSE results are presented in Figure 2, where 0 to 1.5 is "within target"; 1.6 to 2.5 is "above target"; 2.6 to 3.5 is "high"; and greater than 3.5 is "extremely high". Bedroom temperatures were mostly "within the target" to "above the target" RMSE while lounge temperatures were mostly "high" to "extremely high". Several iterations with configuration changes related to load and occupancy behavior such as decreasing the internal gains from occupancy, metabolic rate, miscellaneous, and heaters took place to improve the accuracy of the baseline. Afterward, as shown in Figure 3, RMSEs were improved where the bedroom depicted with less "above target" as before and lounge leaned towards "target" to "above target".

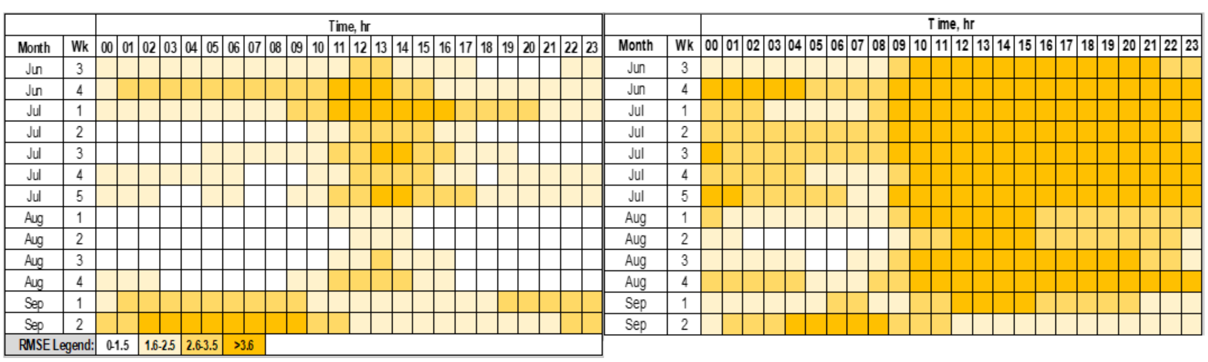

Figure 2 Dry-bulb temperature RMSE between the monitored and initial model of the first-floor bedroom (left) and lounge (right).

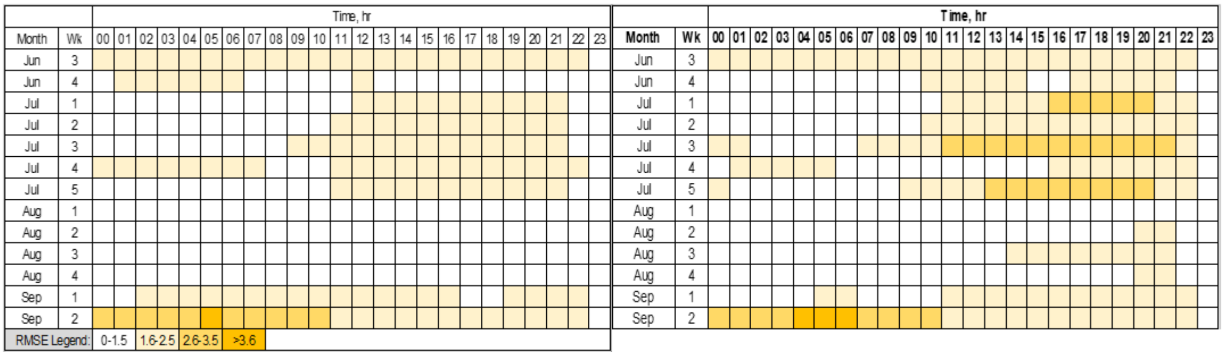

Figure 3 Dry-bulb temperature RMSE between the monitored and re-configured model of the first-floor bedroom (left) and lounge (right).

Building Adaptation Scenarios and Comfort Evaluation

Table 2 presents a list of scenarios for thermal simulations related to the selected adaptive strategies (window opening and external shading through shutters). Combinations of the strategies were also investigated to quantify their combined impact.

Table 2. List of Building Adaptation Scenarios.

Adaptation scenario	ID	Description
Baseline	B	Windows are closed all day and night and exterior shading is not in use
Window opening (night)	W9	Windows are open from 9 pm to 7 am
Window opening (evening and night)	W6	Windows are open from 6 pm to 7 am
Window opening (day)	W7	Windows are open from 7 am to 9 pm
Closing of exterior shading	S	Closing of exterior shutters from 7 am to 9 pm while windows are closed
Window opening from night and closing the exterior shading at day	C9	Combination of “W9” and “S”
Window opening from evening and closing the exterior shading at day	C6	Combination of “W6” and “S”

The suggested indoor temperature limit of 26 °C (78.8 °F) by PHE (2015) to prevent heat-related deaths and illnesses was used in assessing overheating. Regarding RH, although limited guidance exists, a local environmental design guideline in the UK (CIBSE Guide A, 2021) suggests a range of 30-70% to avoid feelings of sultriness or oppression or a more conservative range of 40-60% for conditioned spaces to prevent the build-up of static electricity and condensation and microbial growth. Following this recommendation, the narrower range of 40-60% was found to be a reasonable comfort range for frail occupants such as older adults in care homes. Gupta et al. (2021) also used this comfort range in their recent evaluation study of care homes. The effectiveness of each adaptation was quantified according to the amount of time when operative temperature (T_o) and RH exceeded the selected thresholds for the said summertime period previously.

Future Weather File

The baseline and models with adaptations were simulated using the UK Climate Projections (UKCP) 2009 (Eames, Kershaw and Coley 2011; Hadley Centre for Climate Prediction and Research 2017) design summer year 1 (DSY1) of 2080s of Heathrow with 90th centile probability, high-emissions scenario. It was chosen to represent the worst-case future weather under the climate change projection and was considered to become common given the 2022 heatwave in the UK. The 2080s weather file summer mean external temperature is 9.2 °C (48.6°F) above the mean of the 2019 summer recorded in Heathrow, while the summer mean outdoor RH was 6% below the current weather file.

RESULTS AND DISCUSSION

Assessing the Operative Temperature and Relative Humidity

Figure 4 presents the overheating and humidity discomfort levels of the baseline model under the 2019 and 2080s weather files. Under the 2019 weather, the middle bedroom (B1) and lounge (L1) of the first floor were overheating 54% and 40% of the time, respectively. Simultaneously, both rooms had dry air (<40% RH) for 20% of the time while less than 10% incidence of humid air (>60% RH) was observed. The ground floor bedroom (B0) and lounge (L0) registered lower overheating incidence (8% and 19% of the time, respectively) and experienced less than 10% of dry air but had higher humid air (20% and 30% of the time, respectively).

Under the 2080s climate, overheating in all rooms is expected for almost 100% of the time, but the humid air incidence is expected to decrease. The risk from dry air (<40% RH) in upper rooms will likely increase more than twice compared to the current weather, which means that dry air will be prevalent for about half of the summer. Humid air (RH >60%) incidence in ground floor rooms will drop to less than 5% of the time, while an increase in dry air incidence is expected but not more than 10% of the time.

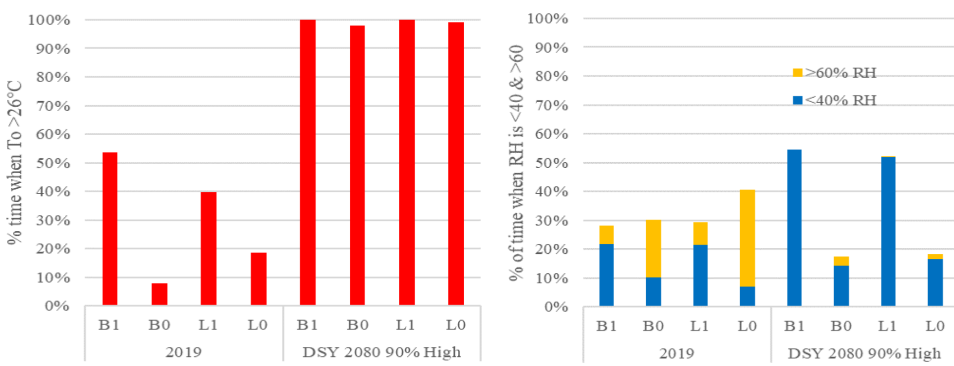

Figure 4 Incidence of T_0 (left) and RH (right) exceeding selected thresholds under the current and future weather files.

The findings regarding overheating under the current weather show a similar trend with the monitoring studies of care homes in London by Gupta et al. (2021) and Oikonomou et al. (2020) and in the monitoring studies conducted in different dwellings across England (Vellei, et al. 2016, Morey, Beizaee and Wright 2020, and Drury, Watson and Lomas 2021), where the upper-floor bedrooms had more hours of overheating than ground-floor bedrooms based on the 26 °C threshold. They are also aligned with remarks of PHE (2015) in the national heatwave plan where upper floors had a higher risk of overheating. This could be due to the fact that higher floors are more exposed to direct sunlight, which increases the rooms' indoor temperature. Also, warm air generated during the day in ground floor tends to rise to the upper floor, as discussed in the literature review by Drury, Watson and Lomas (2021), thereby making them more prone to overheating.

Regarding low RH levels, the findings are similar to two studies from Northern England (Gupta et al., 2016) and London (Oikonomou, Raslan, et al., 2020). High indoor temperatures on the upper floors could be due to high solar gain, in combination to lack of ventilation and heat gains from people and equipment; thus, indoor air becomes warmer and RH is reduced. In contrast, the less likely to overheat ground floor rooms are more likely to have humid air under the current weather. One possible reason might be the reduced exposure of these rooms to direct sunlight, which may translate to lower indoor air temperature and higher RH (Seppänen and Kurnitski 2009).

The Impact of Adaptation Strategies

Figure 5 shows the impact of adaptation scenarios on the temperature and humidity levels of the selected bedrooms and lounges under the current and future climate. The result for each room is ranked from highest to lowest incidence of overheating to easily compare the impact of each scenario on both overheating and humidity discomfort. Overall, all adaptation scenarios show a high potential reduction in overheating, with an increased incidence of high RH (>60% RH) in all rooms, particularly under the ones with window opening.

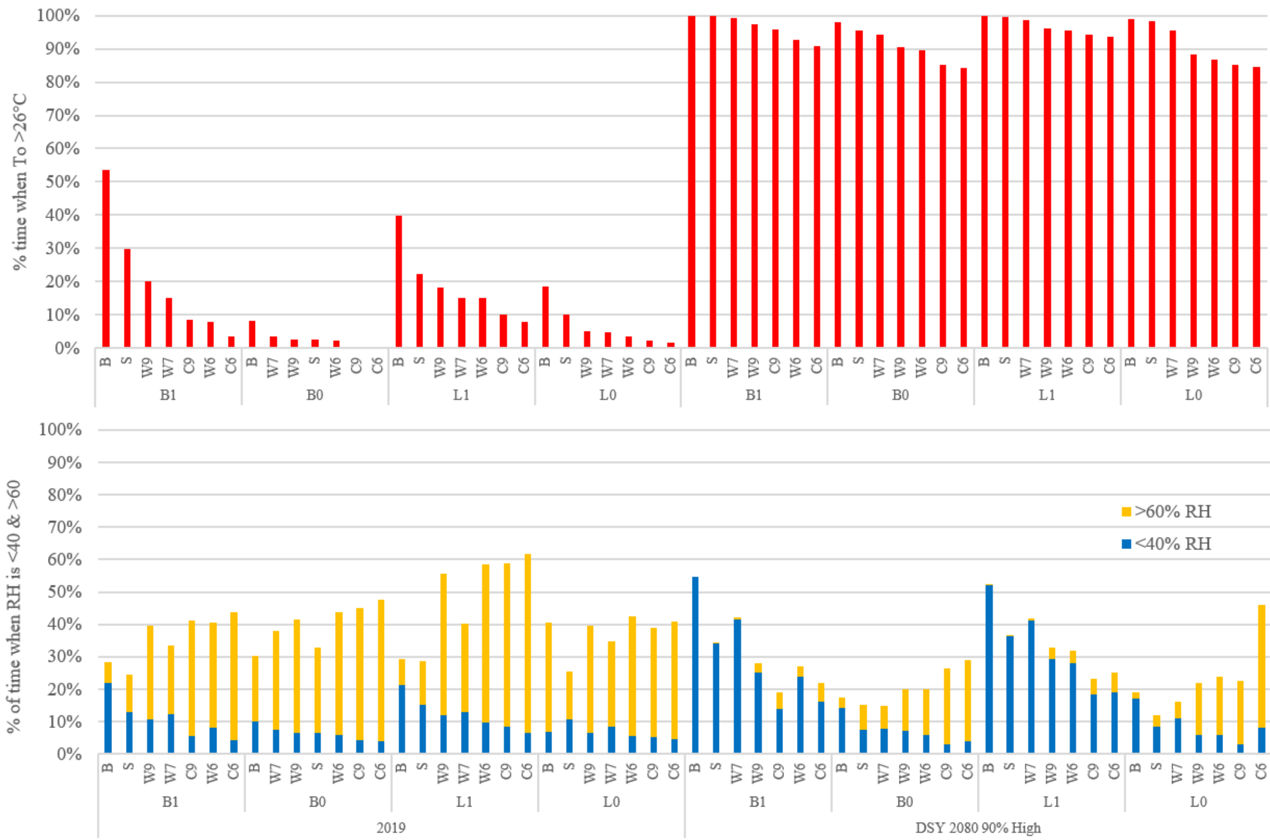

Figure 5 Impact of adaptation scenarios on overheating (top) and low and high RH (bottom) incidences under the current and future weather files.

Under the current weather, the combination of closing shutters during the day and opening windows from 6 PM to 7 AM ("C6") offers the highest reduction in overheating but consistently intensifies the incidence of humid air for all rooms. With this adaptation, bedroom "B0" does not register overheating incidence while first floor "B1" and "L1" benefit the most with reductions in overheating by 50% and 32% of the time, respectively. Inversely, the humid air incidences on both first-floor rooms remarkably increase five times compared to the baseline scenario.

Other adaptations show similar trade-offs between overheating and relative humidity. Among the window opening related scenarios without closing of shutters, opening windows from 6 PM to 7 AM ("W6") results in the lowest possible overheating risk but has the highest increase in humid air incidence. Meanwhile, closing of shutters ("S") generally performs the lowest in overheating reduction, but it presents the lowest combined incidences of dry and humid air for all rooms.

Under the future weather, the risk of overheating is expected to increase substantially for all rooms even under all adaptation scenarios. The combination of closing shutters at day and opening windows from 6 PM to 7 AM ("C6") will have the highest decline in overheating for all rooms again, particularly for rooms "B0" and "L0" (84% for bedroom; 85% for lounge). Applying this adaptation to first floor rooms will reduce overheating incidence to 91% for "B1" and 94% for "L1" of the time. On the other hand, adaptation "S" may not decrease the temperature below 26 °C (78.8 °F) in first floor rooms.

The total incidence of low and high RH is expected to be decreased compared to the baseline values, with any scenario.

Under scenarios “C6” and “C9”, all rooms will register a significant decline in dry-air incidence, but ground floor rooms will experience a significant increase in humid air by more than 18% of the time. Dry air will be more common than humid air on first floor rooms with any adaptation, where adaptation “C9” will offer the least incidence of humidity discomfort. Moreover, “S” and “W7” will have negligible humid air incidence.

The high effectiveness of “C6” for all rooms under the current weather is expected, considering that indoor heat is released through the open windows, and solar heat gain can be minimized by shading. Similar to the findings by Mavrogianni et al. (2014) in retrofitted dwellings, combining late afternoon open windows and closed shutters during the day offers a high reduction in indoor air temperature and overheating risk for bedrooms and lounges. However, this combination does not fully prevent overheating, particularly in first-floor rooms and especially under future weather conditions. This is related to a substantial expected increase in outdoor temperature (by 9.2 °C or 48.6°F summer mean temperature), which suggests that passive ventilation alone may be insufficient for cooling. In the future, hot days will be followed by hot nights thus not offering respite from the heat even with the proposed adaptations, and from an epidemiological perspective, this may increase the heat-related morbidity and mortality risk (Murage, Hajat and Kovats 2017).

Yet, “C6” is also linked to a considerable increase in RH in all rooms under the 2019 weather. This could be from the humid air coming from outside, combined with condensation of accumulated moist air under a cold indoor environment. Conversely, under future weather conditions, the risk of dry indoor air is expected to become more apparent in upper rooms for all adaptation strategies. Together, both low and high RH levels could adversely affect the health and wellbeing of the residents, as they may prolong the life of infectious pathogens and increase their transmission (Wolkoff 2018). It seems that there are advantages and disadvantages of opening the windows and closing shutters, which suggests that there is a limit in their potential to reduce overheating risk and humidity discomfort.

CONCLUSIONS

In a rapidly warming climate, the indoor environment of care homes may negatively impact occupant health and wellbeing, especially for vulnerable older residents. With several heat-related deaths of seniors from past heatwaves in the UK, the possible incidences of overheating and relative humidity levels outside comfort ranges are of great concern. The present study has assessed in parallel the overheating and humidity discomfort risks under current and future weather conditions in a care home in London and has explored the potential of passive adaptations in reducing these risks.

Overall, the study has showed that the older residents of care homes in the UK are at risk from high indoor temperature and low humidity levels under the current weather, which are expected to worsen under a high-emissions future weather scenario. Regarding the relationship between temperature and humidity, the simulation results have indicated a consistent conflict between the overheating and humidity discomfort risks when it comes to window opening and closing of shutters, both now and in the future. Overheating reduction may be compromised by having a greater risk for humid air. Yet, it has been found that some passive adaptations may work well, specifically a combination of window opening in the evening and closing of shutters during the day. However, they may not be enough to maintain indoor temperature and RH within comfortable levels in bedrooms and lounges in the future. It is, therefore, recommended that care homes employ a combination of passive and active ventilation to maintain indoor environmental comfort, along with saving electricity from active cooling.

Future studies may consider modifying the building operation and occupancy through detailed occupant surveys and thermal diaries in order to increase the accuracy of dynamic thermal simulations. Future investigation may also benefit from larger scale and more detailed monitoring studies of care homes’ indoor environments that besides temperature and humidity could include measurements of airspeed and indoor air quality. Lastly, future research can explore a combination of passive and active ventilation scenarios and how easily they could be implemented in real life.

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