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Indoor environmental quality trade-offs due to summertime natural ventilation in London care homes

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Abstract. We evaluate current and future summertime temperature and indoor air quality (IAQ) in two London care homes, occupied by seniors. We further examine the effect of natural ventilation, aiming to identify strategies that can maintain temperature, CO_2 and key pollutants ($PM_{2.5}$, NO_2) within acceptable ranges. Data come from simulations in DesignBuilder. Results show a higher risk of overheating in the newer care home, with 85% of hourly outputs exceeding 26°C. In addition, bedrooms are much warmer than lounges in both homes, with averages expected to reach 32-35°C by 2050. In terms of IAQ, 65% of $PM_{2.5}$ and NO_2 hourly outputs are within range; however, without any ventilation, the high CO_2 levels are expected to rise by 70-130ppm in 2050, especially in bedrooms of the newer home. Results further indicate that natural ventilation can substantially reduce temperature and CO_2, but at the same time it may increase $PM_{2.5}$ and NO_2 coming from outdoors. Yet, these trade-offs can be reduced through a careful ventilation strategy that considers building-specific characteristics, as well as time of day and duration. Findings suggest a need to focus on the interdependencies among indoor environmental quality outputs and highlight the value of inexpensive and sustainable passive ventilation.

1. Introduction

Warmer summers due to climate change can increase the likelihood of overheating risks and associated adverse health effects [1]. The health impacts of overheating are becoming evident even in countries with a temperate climate like the UK [2], which are culturally unprepared. As a result, UK homes are now increasingly experiencing summertime overheating [3]. Indeed, there has been a high number of publications on overheating risk from the UK in recent years [4], which indicates the magnitude of concern. Some papers focus on vulnerable populations and infrastructure, including older people and those living in nursing and care home facilities. As reported in these studies, such settings have traditionally invested in keeping their residents warm, therefore, they are not well prepared to deal with higher indoor temperatures [5].

Along with overheating risks, a small but growing body of literature reports issues with indoor air quality (IAQ) in nursing and care homes in Europe and in the US, highlighting that even low to moderate levels of pollutants, such as particulate matter (PM) and nitrogen dioxide (NO_2) can cause adverse health effects to older adults [6, 7, 8]. They further suggest that these effects may be more pronounced in the case of poor ventilation.

Several building adaptations have been widely considered for reducing indoor overheating, and focus has shifted towards passive approaches as more sustainable cooling solutions. Natural ventilation (NV) through window opening, and especially night ventilation has been shown to be effective in improving indoor thermal conditions in dwellings [9, 10], and in care homes in particular [11, 12]. At the same time, window opening may highly affect IAQ variables, such as increasing pollutant concentrations coming from outdoor sources [13]. Yet, limited studies have explored the impact of ventilation strategies on indoor air quality in parallel to indoor thermal conditions, especially in care settings.

Given that older adults are more susceptible to the combined effects of indoor overheating and pollutants, and as part of a larger study of adapting UK care homes to climate change, in this work, we evaluate current (2019) and future (2050s) summertime thermal conditions and IAQ and pollutant levels from outdoor sources experienced by seniors in a 14th century old and a 1980s newer care home in London. We further examine the effect of natural ventilation through window opening on these levels, aiming to identify ventilation strategies that can maintain indoor temperature, CO_2 and key air pollutants ($PM_{2.5}$, NO_2) within acceptable ranges.

2. Method

2.1. Case studies

The two care homes (CH) A and B used in this work differ in age, construction type, building typology and occupancy, further described below and shown in Figure 1.

A. Located in central London (urban), CH A is an old, thermally heavyweight, south-facing, 2-story building that was initially constructed as a 14th century monastery and was converted into a care home in 2004. It is naturally ventilated and has a courtyard garden. All bedrooms (single occupancy) are on the 1st floor with south orientation, and no window restrictors.

B. Located in west London (suburban), CH B is a newer medium-weight, south-facing, 3-story building that was constructed in 1980 as a pub and was converted into a care home in 1993. It is naturally ventilated and has a small garden and parking outside. Most bedrooms are of single occupancy, facing southeast or northwest, with 10 cm window restrictors.

2.2. Modelling in DesignBuilder

For our analysis, we used models of the two CH constructed in DesignBuilder V6 [14], a graphical user interface for EnergyPlus V8.9 [15]. Indoor temperature (T) and IAQ (CO_2, $PM_{2.5}$ and NO_2) outputs were obtained through simulations of the thermal and IAQ conditions of bedrooms and lounges in each home for a whole summer (June to September) in 2019 and 2050 under four different ventilation scenarios (Table 1).

Outdoor T inputs for 2019 were obtained from the closest weather stations to the two homes (Northolt and London Weather Centre). For 2050, they were based on Design Summer Year 1 (DSY1) high emissions 50% percentile scenario, UK Climate Projections 2009 (UKCP09) from the Chartered Institution of Building Services Engineers (CIBSE) [14]. Outdoor CO_2 concentration was set at 400 ppm, static for both years, while outdoor $PM_{2.5}$ and NO_2 hourly concentrations were taken from the closest monitoring sites of DEFRA UK for 2019 (Bloomsbury and Harlington) and were assumed to remain the same for 2050 [15].

Additional input assumptions for the models, such as occupancy, lighting, and ventilation rates were based on surveys, observations and walk-throughs undertaken by the team during summer 2019. Specifically, lighting heat gain density was set at 12.7 W/m^2 in both care homes, given that non-efficient lighting was present [16], and lighting schedule was set as on from 6 pm to 11 pm, proportional to floor area. Regarding occupancy, bedrooms were assumed to be continuously occupied by one person, while lounges were assumed to be occupied only in the day (9am to 9pm) by 4 people in care home A and by 15 people in care home B. In addition, 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. The openable window area was set to 50% for care home A and 12.5% for care home B (due to the existence of window restrictors). The % of window opening hours varied based on the simulation scenario (Table 1). The infiltration rate was set at 0.7 ac/h.

For validating the models, monitoring data of indoor temperature and humidity were used that were collected by the team during summer 2019. Average monitored vs modelled temperatures from the same lounges and bedrooms were compared, with temperature differences within a 2°C acceptable range [17], which suggests that the models can be used as a basis for further analysis.

2.3. Standards for evaluating thermal and IAQ levels

For assessing indoor overheating in our analysis, we rely on UK Health Security Agency's recommendation of keeping indoor T below 26°C [18]. For IAQ, we use the World Health Organization's (WHO) recommendations for ambient levels, according to which, the 24-hr means of $PM_{2.5}$ and NO_2 should be less than $15ug/m^3$ and $25ug/m^3$ respectively [19]. Lastly, for CO_2, we use the threshold of 750ppm for daily averages, because according to [20], action is recommended above these levels for vulnerable groups.

	Care Home A	**Care Home B**
		
Gross area	$456.2m^2$	$1,574m^2$
Year built	1348	1980
Stories	2	3
Height	3.7m	2.3m
Occupants	8	38
Roof	Unoccupied pitched	Partly pitched/partly flat
Ground floor	Solid, uninsulated	Solid, uninsulated
External wall	Stone, uninsulated	Brick, cavity wall insulation
Glazing	Single	Double
A/C	1 portable unit in 1st floor lounge	2 portable units in 1st floor lounge
Other cooling	Operation of curtains/windows	Operation of curtains/windows (10cm restrictors at place)

Figure 1. Care homes characteristics

Table 1. NV scenarios for DesignBuilder simulations

ID	Category	Specifications
S0	Baseline	Windows closed 100% of hrs
S1	Morning NV (7am-11am)	Windows closed 83% of hrs
S2	Evening NV (7pm-9-pm)	Windows closed 92% of hrs
S3	Night NV (9pm-7pm)	Windows closed 58% of hrs
S4	Continuous NV	Windows open when outdoor T< indoor T & indoor T>22°C

3. Results

3.1. Indoor environmental quality in the care homes

3.1.1. Overheating assessment. According to the baseline scenario S0 of Table 2, in the older CH A, modelled temperatures averaged 26.5°C (bedroom) and 25.3°C (lounge) during summer 2019. Notably, more than 59% of bedroom outputs were above the threshold of 26°C, with an expected increase to 99.7% under a high emissions scenario in 2050, if no cooling measures are implemented (Figure 2). The risk of overheating appears to be much higher in the more modern CH B; during summer 2019, more than 85% of all T outputs were above 26°C, while bedroom and lounge temperatures averaged 28.6°C and 29.4°C respectively. As shown in Figure 3, an average increase of 4-6°C in the T of both rooms is expected by 2050.

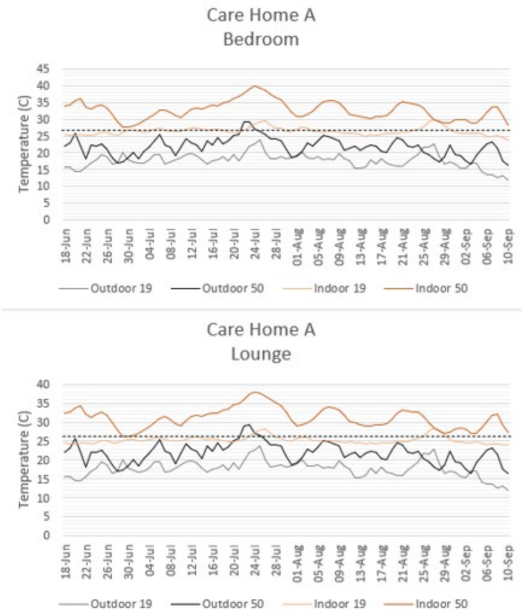

Figure 2. Modelled daily average T in CH A

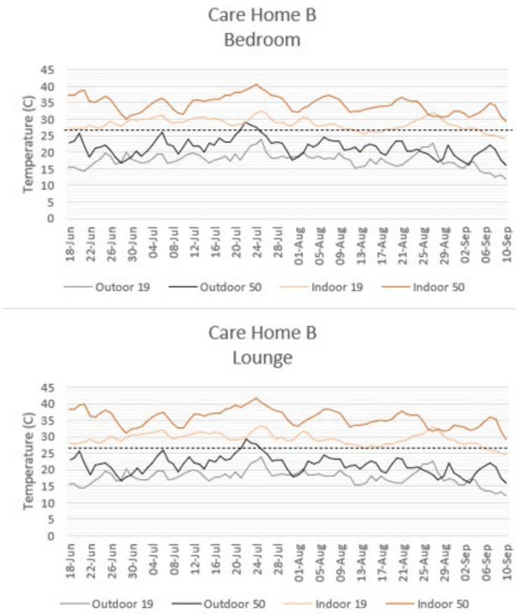

Figure 3. Modelled daily average T in CH B

3.1.2. IAQ assessment. The analysis of IAQ outputs in the care homes indicates a low risk of exposures to $PM_{2.5}$ and NO_2 coming from outdoor sources if no NV is at place (baseline scenario S0 of Table 1). As shown in Table 2, baseline averages remained below the recommended thresholds by WHO in 2019 and no increases are expected in 2050 if outdoor pollutant levels remain the same. In terms of NO_2, similar percentages of outputs are above the WHO threshold in both homes (almost 30%), and in terms of $PM_{2.5}$, slightly higher percentages of outputs are above the thresholds in the older CH (11% in A compared to 5% in B).

In contrast, the average CO_2 levels in both care homes were above the recommended threshold of 750ppm for sensitive groups during summer 2019, with higher concentrations noted in the lounges, likely due to the occupancy assumptions adopted in the models. If no NV is implemented, an average increase of 70-130ppm is expected in the care homes' bedrooms and lounges by 2050.

3.2. The effect of natural ventilation on indoor environmental quality

As highlighted in a previous work [12], natural ventilation through window opening can substantially reduce summertime T inside the care homes, but this depends on the magnitude of the external temperature, ventilation approach, as well as on room- and building-specific characteristics. Here, we extend analysis to assess additional effects on IAQ in parallel to T in the care settings.

As shown in Table 2, it appears that overall, all four NV scenarios presented in Table 1 can substantially reduce summertime T and CO_2 levels inside both rooms of the two care homes. The highest reduction is due to S4 (continuous ventilation with open windows when outdoor T<indoor T and when indoor T>22°C), followed by S3 (night ventilation), and this is consistent across all rooms of the homes in both years.

In the case of CH A, either S3 or S4 can keep T and CO_2 levels within range under current conditions, but only S4 can work well under a high emissions future scenario. However, in the newer CH B, even S4 will not be enough in reducing the risk of overheating by 2050.

Another important finding emerging from this analysis is that in most cases, NV causes an increase in indoor $PM_{2.5}$ and NO_2 coming from outdoor sources. This is especially evident in the case of S2 (evening NV) and its effect on NO_2 in the newer care home for 2019. Likewise, S1 (morning NV) and S2 (evening NV) can increase substantially NO_2 in the older care home for both years, and in the case of S1, average values may go above the WHO threshold of 25ug/m^3. However, in the rest of the cases, such increases are only incremental, which suggests that NV scenarios such as S3 and S4 can work well as a means to cool off and improve IAQ in both settings.

Table 2. Changes in modelled averages by NV scenario in CH A and CH B

	Care Home A								Care Home B							
Bedroom	**2019**				**2050**				**2019**				**2050**			
	T (°C)	CO_2 (ppm)	$PM_{2.5}$ (ug/m^3)	NO_2 (ug/m^3)	T (°C)	CO_2 (ppm)	$PM_{2.5}$ (ug/m^3)	NO_2 (ug/m^3)	T (°C)	CO_2 (ppm)	$PM_{2.5}$ (ug/m^3)	NO_2 (ug/m^3)	T (°C)	CO_2 (ppm)	$PM_{2.5}$ (ug/m^3)	NO_2 (ug/m^3)
S0: Baseline	26.49	791.51	8.08	22.14	32.80	870.40	5.61	22.51	28.61	1031.36	6.70	22.49	34.65	1131.52	5.90	21.78
Change from baseline after NV scenarios																
S1: morning NV	-0.65	-110.35	-0.04	**0.53**	-2.72	-135.97	**0.03**	**3.56**	-1.37	-142.97	-0.08	-1.43	-2.14	-124.69	-0.06	-1.21
S2: evening NV	-0.57	-108.36	**0.10**	**1.27**	-1.41	-148.33	**0.05**	**1.54**	-1.17	-115.74	**0.05**	**2.24**	-1.26	-159.59	**0.06**	-0.72
S3: night NV	-1.08	-200.59	**0.15**	**0.63**	-4.56	-250.93	**0.15**	**0.26**	-2.56	-192.70	**0.23**	**0.3**	-4.78	-183.29	**0.28**	0
S4: continuous NV	-2.31	-381.60	0	**0.55**	-7.16	-455.85	-0.03	**0.11**	-4.35	-550.80	0	-0.21	-6.82	-606.32	**0.03**	**0.4**
Lounge	**2019**				**2050**				**2019**				**2050**			
	T (°C)	CO_2 (ppm)	$PM_{2.5}$ (ug/m^3)	NO_2 (ug/m^3)	T (°C)	CO_2 (ppm)	$PM_{2.5}$ (ug/m^3)	NO_2 (ug/m^3)	T (°C)	CO_2 (ppm)	$PM_{2.5}$ (ug/m^3)	NO_2 (ug/m^3)	T (°C)	CO_2 (ppm)	$PM_{2.5}$ (ug/m^3)	NO_2 (ug/m^3)
S0: Baseline	25.30	845.95	8.08	22.19	31.18	931.02	5.61	22.51	29.42	1162.64	6.70	22.51	35.72	1289.86	5.90	21.89
Change from baseline after NV scenarios																
S1: morning NV	-0.36	-121.09	-0.04	**0.53**	-2.28	-146.51	**0.03**	**3.19**	-1.23	-152.01	-0.07	-1.38	-2.16	-136.45	**0.06**	-1.25
S2: evening NV	-0.45	-122.65	**0.11**	**1.29**	-1.31	-159.30	**0.05**	**1.56**	-1.17	-124.62	**0.05**	**2.18**	-1.26	-169.60	**0.06**	-0.76
S3: night NV	-0.96	-139.50	**0.15**	**0.57**	-3.92	-196.29	**0.15**	**0.26**	-2.31	-175.96	**0.22**	**0.27**	-4.86	-201.00	**0.29**	0
S4: continuous NV	-1.42	-423.19	**0.04**	**0.63**	-5.86	-500.49	-0.02	**0.11**	-4.43	-609.89	-0.01	-0.24	-7.02	-673.36	**0.03**	**0.29**

4. Conclusion

In this modelling study, we assessed the summertime thermal conditions (T), CO_2, and pollutant levels ($PM_{2.5}$ and NO_2) from outdoor sources, experienced by seniors living in two care homes in London with varied characteristics. Our analysis focused on representative bedrooms and lounges within each home and considered current-2019 and future-2050s (high emissions) temperature and air quality. Results from the baseline models showed that there is a higher risk of overheating in the newer care home, which is expected to worsen in the future. This is consistent with the findings of other studies [5, 12] and has implications for the type of insulation as well as the existence of window restrictors usually found in newer buildings and their impacts on a building's thermal performance. Results also highlighted that without any natural ventilation, the risk of overheating is higher in the bedrooms of the care homes, while lounges will experience higher levels of CO_2, which is frequently reported in the literature of IAQ in nursing and care centers [6, 7]. At the same time, and assuming absence of indoor sources, $PM_{2.5}$ and NO_2 levels can be kept within acceptable ranges, likely due to the absence of ambient pollutant ingress.

In our analysis, we further tested the effect of four NV scenarios on indoor T and IAQ levels. Results showed that overall, natural ventilation through window opening can be highly beneficial in improving indoor thermal and CO_2 levels, but it can increase $PM_{2.5}$ and NO_2 coming from outdoors. However, these trade-offs were higher only under specific NV scenarios, suggesting that strategies such as night ventilation or continuous ventilation depending on indoor and outdoor temperature can still be utilized for improved indoor environmental quality. This finding highlights the importance of bringing IAQ as an equally important consideration in the assessment of indoor environments for older adults. In addition, it illustrates the potential of an inexpensive and sustainable passive adaptation in reducing indoor heat and pollutant exposures. In future work, we will explore additional NV scenarios that depend on outdoor air quality in parallel to outdoor temperatures and we will consider variations in outdoor air quality levels.

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